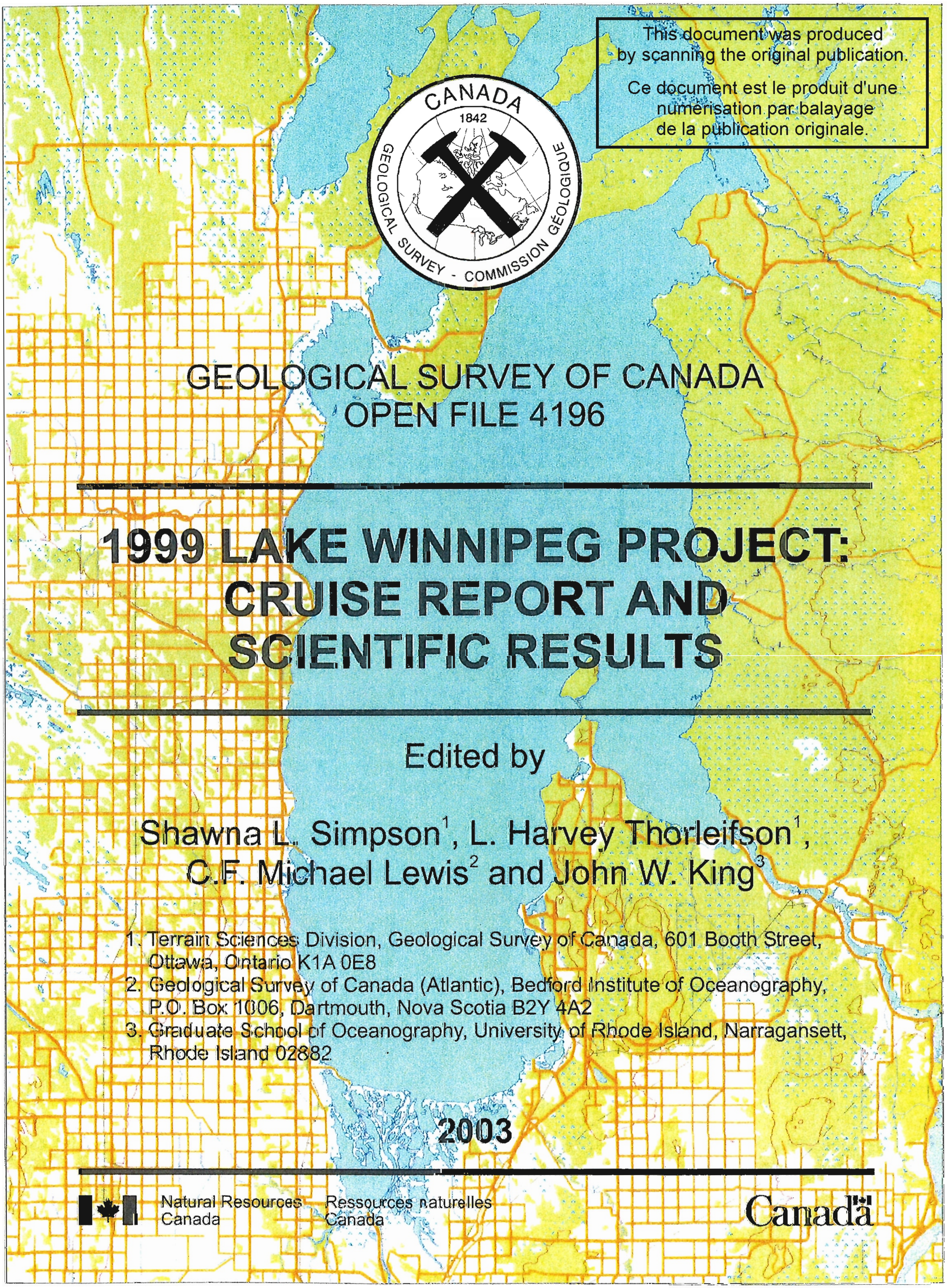

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GEOLOGICAL SURVEY OF CANADA
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1999 LAKE WINNIPEG PROJECT: CRUISE REPORT AND SCIENTIFIC RESULTS

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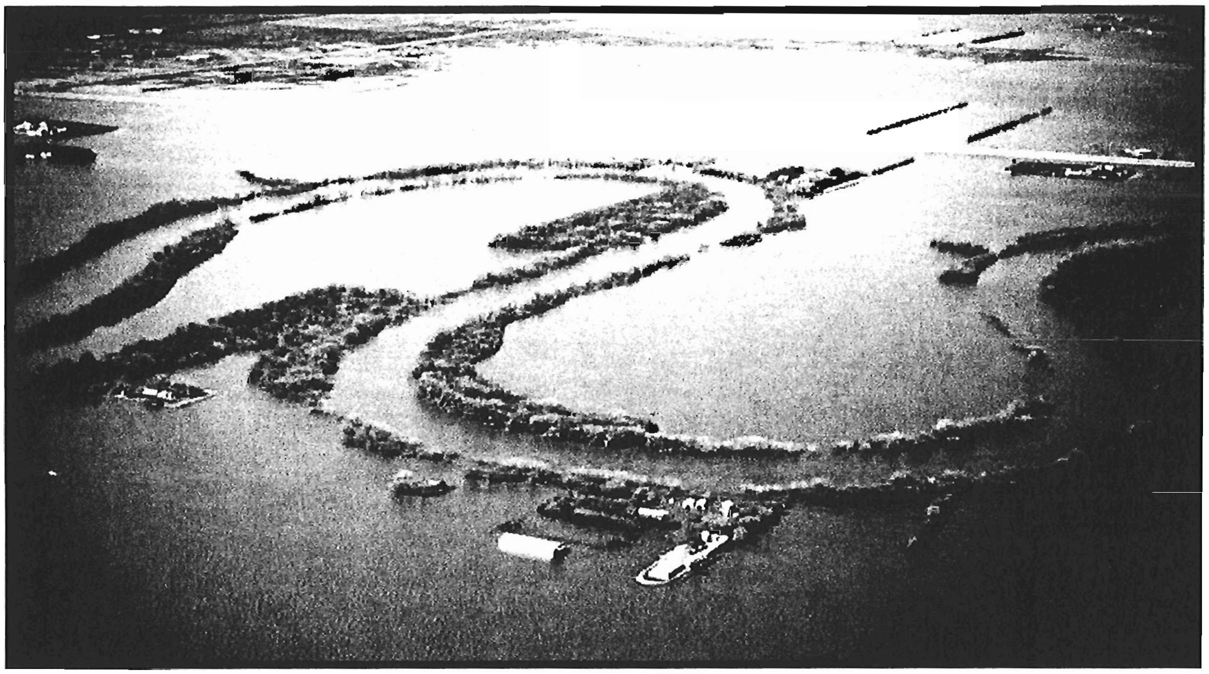

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1997 Red River flood

1. Executive summary

1. Executive Summary

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ABSTRACT

Following the 1997 Red River flood, a program of research was initiated to determine how large the floods can be, how often large floods have occurred in recent centuries, and whether natural factors may be changing the flood risk. As part of this program, 15 cores were collected from the south basin of Lake Winnipeg. Paleomagnetic profiles were used to select three apparently undisturbed, high-sedimentation-rate cores for detailed chemical, physical, and biological analyses, to assess whether Red River floods are recognizable in the lake. A thousand-year paleomagnetic chronology was confirmed and augmented by Cs-137, Pb-210, palynology, radiocarbon dating, and inorganic geochemical relative age markers. While some parameters exhibit multi-century fluctuations, varying excursions, and 20th century shifts, grain-size results show the clearest signal of recurring events. Several layers of enhanced silt, 1-4 cm thick, with 6-15 % more silt than background are present, in several cases correlating core to core. A Red River flood origin for these silt excursions is plausible. The results also provide indications of increased contamination, nutrient influx, and more rapid sedimentation in the 20th century.

INTRODUCTION

The Red River flood of 1997 was a major disaster that drove 103,000 people from their homes. Much is being done, however, to reduce comparable damage and disruption in the future through enhanced dikes and diversions, as well as revised land use and water management practices. The design of these works requires an optimal understanding of the risk. Research therefore has addressed the nature of the largest known flood, in 1826, whether comparable large floods have occurred in recent centuries, and how geomorphic, climatic, land use, and tectonic factors may be changing the flood hazard. These issues are being addressed by examining the geomorphic processes governing evolution of the Red River, archival records of flood history, floodplain stratigraphic records, tree-ring records, changes in valley gradients, and by examining the stratigraphy of Lake Winnipeg sediments (Thorleifson et al., 1998). The coring in Lake Winnipeg, receiving basin of waters from the Red River, was designed to sample sites most likely to have recorded any influx of sediments from the Red River that may have occurred. To do so, 15 cores, each about 1.5 m long, were collected from the south basin during a cruise of the Canadian Coast Guard Ship (CCGS) Namao in August 1999, designated Geological Survey of Canada (GSC) cruise 99-900. In addition to recording gradual changes in Red River sediment transport, it was thought that flood events might be recognizable, due to unique properties allowing differentiation from other sediments in the lake, although it was unclear what attribute would best distinguish flood-related sediments. The cores therefore were thoroughly analyzed for chronology, as well as for a broad range of physical, chemical and biological properties to determine which, if any, would record a history of flooding.[*]

While examining the Lake Winnipeg record for evidence of floods, it became evident that some of the physical, chemical and biological properties examined exhibited significant changes in the top 20 cm of the cores, providing a record of 20th century change in the basin. Many of these changes seem attributable to human activity, including changes in landscape use and industrial development.

The purpose of this open file is to document the acquisition and investigation of the cores, and to present preliminary interpretations of the project data as a record of Red River flooding history, and of environmental change in the Red River basin over the last millennium.

LAKE WINNIPEG

Lake Winnipeg, located in central North America, is the eleventh largest lake in the world, having an area of 24,000 km^2 (Hutchinson, 1975). The lake straddles the contact between Paleozoic carbonate rocks to the west and Precambrian igneous and metamorphic rocks of the Canadian Shield to the east. A smaller south basin, approximately 90 km by 40 km, is separated from a north basin, approximately 240 km by 100 km, by a narrow passage known as The Narrows. The glacially-scoured depression in the rocks underlying the lake, with a depth of 50-100 m, is largely filled with fine-grained glacial Lake Agassiz sediments, overlain by up to 15 m of post-glacial

[*] Italicized text is repeated in each chapter

Lake Winnipeg sediments (Todd and Lewis, 1996). The bathymetry of the lake is shallow and the bottom is flat, with depths averaging 9 m in the south basin and 16 m in the north basin. The lake has a catchment area extending from the Rocky Mountains to very near Lake Superior, including the basins of the Winnipeg, Saskatchewan, Red, Dauphin and numerous smaller rivers. Outflow from the lake is north to Hudson Bay, through the Nelson River. Post-glacial uplift has caused the north end of the basin to rise relative to the south, causing a gradual rise of lake levels that continues at present (Lewis et al., 2000). The mean annual temperature of the region, recorded at Gimli, is +1.4°C, although the continental climate of the region ranges from hot summers to very cold winters. The mean annual precipitation is 50.8 cm. The lake is ice free from early May to late November (Ice Thickness Climatology, 1992) and ice cover from November to May is consistently thick and continuous. The lake waters are poorly stratified to unstratified and during the summer months water temperatures range from +17°C in the north basin to +19.5°C in the south basin (Todd, 1996), hence bottom sediment temperatures are equally warm in mid-summer. The lake supports a commercial fishery, it is a major destination for recreation, and lake levels are regulated to optimize hydroelectric power generation on the Nelson River.

LAKE WINNIPEG PROJECT

The Lake Winnipeg Project was launched by the Geological Survey of Canada and Manitoba Geological Survey in 1994 to support management of issues such as shoreline erosion. A four-week cruise of the Canadian Coast Guard Ship (CCGS) *Namao* in 1994 (GSC Cruise 94-900) was followed by a similar effort in 1996 (96-900), shoreline investigations in 1997 (97-900), the one-day cruise in 1999 described in this open file (99-900), as well as ongoing measurement of uplift and small vessel work. The 1994 cruise included bottom-sediment, biological and water sampling, geophysical surveys (low frequency air gun seismic, high frequency seismic and sidescan sonar), gravity and piston coring at 13 sites, and box coring at 10 sites (Todd et al., 1996). The 1996 cruise focused on confirmation and dating of the southward migration of the lake, and scouring of the lake bottom by ice, and included similar geophysical surveys and core collection (Todd et al., 2000). The 1997 activity focused on shoreline processes in the western south basin.

1999 *NAMAO* CRUISE

Selection of five sampling sites in the central south basin of Lake Winnipeg (Lewis et al., this volume) was based on proximity to the Red River mouth and on the absence of ice scour on sidescan sonar records previously obtained in 1994 (Todd et al., 1998; McKinnon et al., 2000). Site 1 was located at the latitude of Gimli. Site 5, at the latitude of Winnipeg Beach, was the southernmost point on the north-south survey line that lacked ice scour. Sampling was conducted in calm weather on August 24, 1999 from the CCGS Namao. Three cores were obtained at each of the five sites using a gravity corer consisting of a 100 kg weightstand over a 2 m steel pipe with a 10 cm diameter plastic liner tube. Sites were sampled from north to south, and cores 1 to 3 were obtained from the most northerly site, hence cores 12-15 were from the most southerly. The length of the cores ranged from 107 cm to 170 cm. The cores were sealed, labelled and transported to Gimli, Manitoba on August 29, where they were refrigerated, and subsequently transported via refrigerated truck to the GSC Atlantic core storage facility in Dartmouth, N.S. A monitoring device attached to the core bundle indicated that the sediments did not exceed a temperature of 19°C at any time during transport.

PHYSICAL AND PALEOMAGNETIC PROPERTIES

Ten weeks following collection, whole core physical property (GEOTEK® logging) and paleomagnetic analyses for all 15 cores were completed at the University of Rhode Island, to assess the character of the sediments, test for the presence of trends and/or events in offshore sedimentation, and to obtain preliminary age models prior to selection and splitting of cores (King et al., this volume). Recurrent physical property trends and coherent paleomagnetic inclination trends indicated that most of the cores are of high quality, not disturbed, and that data from selected cores are likely to be representative of the offshore sediments. Paleo secular variation (PSV) records of the cores were correlated to a radiocarbon-dated regional PSV curve. Paleomagnetic inclination marker I0 was inconsistently identified in the cores. Paleomagnetic inclination marker I1, previously dated between 870 and 1190 yrs BP in lakes in Oregon and Minnesota, was identified in the lower portion of the majority of the cores, thus indicating that the cores represent about 1000 years of sedimentation. The I1 marker was subsequently dated at 810 ± 35 yrs BP (CAMS-84850), calibrated to AD 1230 +50/-70, using an AMS radiocarbon date of an insect sample at the depth of the I1 marker in one of the cores. Correlation of the I1 marker indicated more rapid sedimentation at the more northerly sites. Six cores, at least one from each site, were split and described. Sediments in the split cores all consist of apparently massive to diffusely laminated soft, dark olive grey, noncalcareous silt and clay with black streaks and mottling related to iron sulphide. Based on these observations, but with preference for sites closest to the Red River mouth, core 8 from the 3rd most northerly, core 4 from the 2nd most northerly, and core 3 from the most northerly site, were selected for detailed sampling at 1-cm spacing, permitting subsequent radiochemical, textural, elemental, Rock-Eval organic, and carbon/nitrogen elemental/isotopic analyses, and palynological analysis. Cores 5, 7 and 9 were sampled at 5-cm spacing for radiocarbon dating and macrofossil analysis.

RADIOCARBON DATING

Entire half cores from cores 5, 7, and 9 were processed to obtain macrofossils to obtain samples for radiocarbon dating (Telka, this volume, a). Because macrofossils are sparse in the sediments, the entire half-core was subsampled at 5-cm spacing. Concurrently, good chronological control was obtained from radiochemistry and pollen for the most recent 150 years, in addition to the I1 paleomagnetic inclination marker lower in the cores. The radiocarbon samples therefore were selected from the lower portion of the core to provide a date for the I1 marker in Lake Winnipeg, and from the middle portion of the core to fill the gap where dates were not available. Two samples from core 9, insect remains from an individual aquatic insect, and a rounded terrestrial wood fragment, were selected and submitted for radiocarbon dating. The insect material at 110-115 cm depth provided excellent corroboration of the magnetic record at 810 ± 35 yrs BP (CAMS-84850). The rounded wood sample at 50-55 cm depth is interpreted as reworked, the wood being 2 to 3 centuries older than the enclosing sediment. Nevertheless, the analysis provides a useful maximum age.

PB-210 DATING

Cores 4 and 8, sliced at 1-cm spacing, were analyzed radiochemically to obtain ages and sedimentation rates for the past one and a half centuries (Wilkinson and Simpson, this volume). Lead-210 ages were determined from unsupported Pb-210 activity, using the Constant Rate of Supply (CRS) method, for the upper 34-35 cm of the cores. The results indicate an age of AD 1900 at ~25-26 cm depth in core 4 and ~27-28 cm depth in core 8. The peak Cs-137 activity in the cores, at 12-13 cm in core 4 and 13-14 cm in core 8, was attributed to the period of peak fallout from atmospheric nuclear bomb testing. This peak occurred in the mid 1960's as a result of the signing of the Limited Test Ban Treaty in 1963, which banned atmospheric testing of nuclear devices. The integrity of the Pb-210 dates is confirmed by a Pb-210 date for peak Cs-137 in the mid 1960's. A second and later Cs-137 peak of lesser magnitude is dated from Pb-210 results at 1985 (6-7 cm) in core 4 and 1984 (7-8 cm) in core 8. This second peak is attributed to contamination of the basin, possibly from a documented spill that occurred at the Whiteshell Nuclear Research Establishment at Pinawa in 1979 (Guthrie and Acres, 1980). The occurrence of Cs-137 in the cores below 1952 levels is likely the result of slight smearing during coring. Average sedimentation rates for the measured interval, using the CRS method, were higher for core 8 (861 $g/m^2/yr$) than for core 4 (635 $g/m^2/yr$). Up-core increases in sedimentation rates were observed in both cores.

The post-1850 chronology, based on Pb-210 and Cs-137 for cores 4 and 8, was augmented with a *Salsola* marker (Anderson, this volume). Chronology for the top 15 cm of core 3 was estimated by averaging Pb-210 ages obtained from the tops of cores 4 and 8. Given that the *Salsola* marker occurs at similar depths in all three cores, and that intact Pb-210, paleomagnetic and geochemical profiles indicate continuous sedimentation, it was assumed that the chronological profile for core 3 would be similar to that defined by Pb-210 dates in cores 4 and 8. Core 3 chronology between 15 and 27 cm was estimated by linear interpolation between a Cd marker at 15 cm (Simpson and Thorleifson, this volume, a), dated at 1936 (1932-1940) from an average of core 4 and core 8 ages, and the *Salsola* marker at 27 cm, dated at 1888. Peak Cs-137 activity and the first sustained occurrence of *Salsola* pollen are generally within the error ranges assigned for Pb-210 dating confirming that the ranges of estimated error are reasonable.

A preliminary chronology for the lower portion of the cores was provided by interpolation between Pb-210 or *Salsola* (core 3) and the paleomagnetic inclination marker I1 (810 ± 35 yrs BP; CAMS-84850) in core 9 (King et al., this volume). The ages were then re-adjusted to ensure a consistent age for the inorganic geochemical markers in each core. A three-core average age was determined for each geochemical marker using the preliminary ages. Then ages between the geochemical markers were calculated by linear interpolation between the markers.

Sedimentation rates shift from an average of 1.3-1.5 mm/yr in the pre-1900 period to an average of 2.6 mm/yr for the post-1900 portion of the cores. This shift is attributed either to post-depositional compaction or to an increase in sediment derived from enhanced runoff caused by landscape changes in the early 20th century, or to a combination of the two. The pre-20th century sedimentation rate exceeds the previous sedimentation rate estimate of 1 mm/yr based on the 4000-yr record of south basin Lake Winnipeg sedimentation (Vance and Telka, 1998), implying that average sedimentation rates during the last 1000 years may have been slightly greater than the three preceding millennia.

TEXTURAL ANALYSIS

Textural analysis of cores 3, 4 and 8 was used to test for the presence of trends and/or events in offshore sedimentation (Simpson and Thorleifson, this volume, b). The sediments consist entirely of silt and clay, averaging 40 % silt and 60 % clay. Decimeter- and centimeter-scale textural variations are evident throughout the cores, exhibiting several broad silt maxima as well as numerous layers of greater silt content, 6-15 % greater than background, respectively. Decimeter-scale silt layers are thought to be the result of shifts in sediment source areas, perhaps brought about by climatic or other factors, while centimeter-scale layers occurring about once per century are most likely attributed to Red River floods. A steady up-core increase in silt, observable throughout the top 25 cm, is attributed to 20th century changes in land use, particularly the expansion of agriculture and drainage, both promoting runoff.

ELEMENTAL ANALYSIS

Elemental analysis of cores 3, 4 and 8 was also used to provide a record of compositional variations and test for the presence of trends and/or events in offshore sedimentation (Simpson and Thorleifson, this volume, a). Many of the 41 elements analyzed show monotonous records. Ca, Mg and Cd, however, show correlatable, decimeter-scale variations throughout the record. Ca and Mg show a strong positive correlation with each other, and some increases correlate with those in silt content. Variations in Cd correlate with the abrupt shifts in silt content in core 4, but do not correlate with silt in the other two cores. Increases in the concentrations of some trace metals, including Ag, Cd, Cu, Hg, Pb, Sb, U and Zn, as well as P, in the top 25 cm of the cores, are in some cases considered to be of sufficient magnitude to be attributed to anthropogenic inputs. In most cases the concentration of these elements levels off or decreases in the top 10 cm, implying recent reductions in inputs. Trends in the upper portion of the cores that are correlatable from core to core are also a useful confirmation of core integrity.

PHOSPHORUS FORMS

Significant increases in sediment P concentrations were observed in the uppermost 20 cm of cores 4 and 8, and anomalies in concentration were observed at depth (Mayer et al., this volume). In order to better interpret the causes of these trends, total phosphorus was re-analyzed by ignition, and forms of phosphorus were determined using sequential extraction. The analysis was augmented using a box core collected in 1994. Three forms of P, non-apatite inorganic P, apatite P, and organic P, were determined. A doubling in total P relative to Al over the last 50 years is largely due to increases in the non-apatite inorganic P fraction, often associated with anthropogenic sources, suggesting that much of the sedimentary P increase is attributable to changes in the nutrient status of the water column related to anthropogenic inputs. Organic phosphorus exhibits a subtle increase in concentration in the upper 20 cm, likely the result of increases in the primary productivity of the lake. Apatite P, which is thought to be of detrital origin, remains fairly constant over the length of the cores, although a slight increase with depth, in longer cores, is attributed to the diagenetic formation of this mineral and/or shift in supply of detrital material. Anomalous spikes in P concentration deeper in the cores, comprised mainly of the non-apatite inorganic P fraction, likely result from natural variations in local oxidizing conditions, possibly induced by changes in water circulation.

ROCK-EVAL ORGANIC ANALYSIS

Rock-Eval analysis, a means for determining the forms of organic material, of cores 4 and 8 was also completed, primarily to test for influxes of terrestrial organic material during floods (Snowdon and Simpson, this volume). The results, in particular hydrogen and oxygen indices, implied that most of the lacustrine organic matter (OM) was either derived from terrestrial sources, or was significantly altered by diagenesis. With the aid of additional information from carbon and nitrogen elemental and carbon isotopic analyses, it appears most likely that the lacustrine OM was primarily derived from aquatic sources, but has undergone alteration. Lack of a corresponding down-core decrease indicates that the majority of the OM alteration occurred in the water column under oxidizing conditions, prior to deposition. Diagenetic alteration likely continued after deposition at a slower rate. Large shifts in Rock-Eval properties in the top 22 cm of the cores have likely resulted from a combination of processes, including increases in sedimentation rate, changes in productivity, and the time required for OM to degrade to background levels. Co-variant increases of metals with total organic carbon could be the result of continual migration of and biological recycling of metals in the upper 20 cm of the lake-bottom sediments. Anomalies readily attributable to floods were not observed, either indicating that the terrestrial OM is indistinguishable from the altered lacustrine OM, or because any influx of terrestrial organic matter that occurs during a flood is insignificant relative to background accumulation of lacustrine organic matter.

CARBON AND NITROGEN ELEMENTAL AND ISOTOPE ANALYSIS

Carbon and nitrogen elemental and isotopic analyses were completed for core 8 only (Buhay and Simpson, this volume). Organic carbon and nitrogen contents of the offshore sediments are low, together comprising less than 2 % of the total material. Carbon-nitrogen ratios and carbon isotopic compositions suggest that lacustrine organic matter in the offshore sediments is derived almost exclusively from lacustrine algae. Diagenetic alteration of organic matter is generally extensive in oxic lakes, however, this process does not appear to have significantly altered C/N_{org} ratios and $\delta^{13}C_{org}$ values of Lake Winnipeg sediments. The constancy of the carbon and nitrogen record over the past 1100 years, excluding a shift in the twentieth century, indicates that environmental conditions, such as climate, watershed dynamics and transport mechanisms, have not changed sufficiently during this time to affect these values. However, enrichment of carbon and nitrogen isotopic values at the top of the core suggests that the use of nitrogen fertilizers in the latter half of the 20th century caused increased nitrogen flux to the lake and subsequently enhanced algal productivity, which could be contributing to eutrophication of the lake. Several centimeter-scale layers of depleted $\delta^{13}C_{org}$ content were identified and could have arisen due to nutrient influxes associated with flood events. However, other processes cannot be ruled out for the formation of these layers. Although some of the layers correspond to some of the known floods of the past 200 years, further research on another core is required to corroborate the findings.

MACROFOSSIL ANALYSIS

Macrofossils recovered from cores 5, 7 and 9 for radiocarbon dating were also examined to support paleoenvironmental analysis (Telka, this volume, b). The macrofossil record is dominated by aquatic fauna, suggesting that deep-water conditions have persisted for the past 1100 years. A comparison to macrofossil abundance in nearshore deposits indicates that the transport of coarse terrestrial organic material to these deeper waters is rare. Evidence of floods, in the form of correlatable layers rich in terrestrially-derived material, was not observed. Four-fold increases in macrofossil abundance, and in the insect group Chironomidae, in the top 20-30 cm of the cores implies that nutrient influx began to increase during the period AD 1874 to AD 1934. There is no indication in the form of pre-20th century diminishing numbers or partially-decomposed fossils that the down-core decrease is due to post-burial decomposition. The occurrence of intervals rich in charred remains may indicate the occurrence of fires in AD 1912-1929, AD 1429-1461 and AD 1024-1056.

PALYNOLOGICAL ANALYSIS

Palynological analysis was completed for core 8 and for the tops of cores 4 and 3, to aid dating, correlation, and paleoenvironmental analysis (Anderson, this volume). A mixture of boreal forest and grassland/parkland taxa dominates the entire record. A basal pollen assemblage zone (zone 3) is dominated by *Pinus* (pine); a middle zone (zone 2) is distinguished by upward-decreasing percentages of *Pinus* and upward-increasing percentages of *Picea* (spruce); and an upper zone (zone 1) is characterized by more abundant weed and grass pollen. The increase in *Picea* and decrease of *Pinus* at the zone 3/2 boundary, dated at ~ AD 1100 based on the age model constructed here from radiochemical, radiocarbon and paleomagnetic dates, is indicative of a cooler climate and is interpreted as the onset of the Little Ice Age. The zone 2/1 boundary is best marked by the first sustained appearance of *Salsola,* dated at ~1895 based on Pb-210. This agrees reasonably well with the probable timing for the arrival of *Salsola* pollen to Lake Winnipeg, which would be about AD 1888 based on agricultural records that document the first appearance of *Salsola* at the headwaters of the Red River. The increase in weed and grass pollen at this boundary is interpreted as the beginning of extensive agricultural development of the lower Red River Valley. *Alnus* (alder) and *Salix* (willow) cycles of undetermined origin were observed throughout the record, but do not appear to correlate core to core.

FLOODS

While some parameters exhibit multi-century fluctuations, varying excursions, and 20th century shifts, grain-size results show the clearest signal of recurring events. Several layers of enhanced silt, 1-4 cm thick, with 6-15 % more silt than background are present, in several cases correlating core to core. Given that previous work on sediment budgets indicates that the offshore south basin sediments are predominantly derived from the Red River, a flood origin for these silt excursions is plausible.

20TH CENTURY

Environmental changes caused by anthropogenic activities are often recorded in lake-bottom sediments (e.g. Mathewes and D'Auria, 1982; Punning et al., 1997; Lockhart et al., 1998), and the study of lake-bottom cores can be useful in reconstructing histories of agricultural activity, growing urbanization, industrial development and other human activities. Although the objective of the 1999 cruise was to assess the Lake Winnipeg sediments for a flood record, while examining the physical, chemical and biological properties of the cores, significant changes in the top 20 cm of the cores were observed. These compositional shifts document changes that began in the late 1800's, many of which are attributable to human activity.

Analysis of the cores has shown that sedimentation rates and to some extent grain size have been increasing since the late 1800's, presumably due to the expansion of agriculture and drainage. Associated increases in Ag, Cd, Cu, Hg, Pb, Sb, U and Zn concentrations since the early 1940's are attributed in some cases to contamination from a variety of local and airborne anthropogenic sources. Concentration plateaus or decreases in the top 10 cm of the cores for several elements imply recent reductions in inputs. Lockhart (1996) and Lockhart et al. (2000) previously documented the accumulation of heavy metals in Lake Winnipeg sediments. A significant influx of Cs-137 seems to have occurred in the mid 1980's, although its impact was less than 1960's atmospheric nuclear weapons testing. This second Cs peak is perhaps attributable to a spill that occurred at the Whiteshell Nuclear Research Establishment at Pinawa in 1979 (Guthrie and Acres, 1980). Parallel increases in the number of macrofossils, $\delta^{13}C$ and $\delta^{15}N$, and non-apatite inorganic phosphorus imply enhanced nutrient influx and lake productivity beginning in the late 1800's and peaking in the past 40 years. Stainton et al. (2002) and

Kling et al. (2002) have documented the changing trophic status of the lake in recent years.

Analysis of the cored sediments thus documents a history of rapid change over the past 100 to 120 years, following a more stable 1000-year history.

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2. Introduction

2. Introduction

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RED RIVER FLOODING

Red River floods are triggered by abrupt spring snowmelt and flows that exceed the capacity of the Red River channel, resulting in extensive inundation of the surrounding flat prairie landscape (Brooks and Nielsen, 2000). The 1997 Red River flood was a major natural disaster that forced the evacuation of 28,000 residents in Canada (Manitoba Water Commission, 1998) and 75,000 residents in the United States (Todhunter, 2001). Damages are estimated at 325 million US dollars in Manitoba (Manitoba Water Commission, 1998) and 4.5 billion US dollars in North Dakota and Minnesota (International Red River Basin Task Force, 2000). Much is being done, however, to reduce comparable damage and disruption in the future through enhanced dikes and diversions, as well as revised land use and water management practices. Planning of enhanced flood protection measures requires an optimal understanding of the risk, including a better understanding of how large the floods can get, how often major floods have occurred, and whether natural factors are changing the flood risk.

Red River flooding and mitigation

The mitigation of Red River floods has been addressed from a structural approach that includes the Red River Floodway that diverts Red River flow around Winnipeg, the Portage Diversion that diverts Assiniboine River (a tributary that joins the Red River at Winnipeg) flow to Lake Manitoba, the Shellmouth Dam that retains water in an upper Assiniboine reservoir, and many kilometers of primary dyking that confine Red River flow through Winnipeg (Mudry et al., 1981). This flood protection infrastructure has been very effective since the opening of the Floodway in 1968, and billions of dollars in flood damages have been avoided, particularly during the 1997 flood (Mudry et al., 1981; International Red River Basin Task Force, 2000). During this flood, the Floodway was utilized to slightly above design capacity (Rannie, 1998), but a minor change in weather conditions could have resulted in a catastrophic dyke failure causing large-scale flooding in Winnipeg (International Red River Basin Task Force, 2000). To reduce the risk of a multi-billion dollar flood disaster, recent studies have proposed enhancing the flood protection infrastructure at Winnipeg, specifically by expanding the Floodway or constructing a detention dam near St. Agathe (International Red River Basin Task Force, 2000; KGS Group, 2001). A key aspect of enhancing the flood protection is defining an adequate design discharge to mitigate against future floods. For design purposes the probability of flooding is generally estimated from the record of measured annual peak flows (Brooks et al., 2002). However, the extrapolated return periods of hypothetical extreme floods can be highly uncertain when the instrumental record is short, if flows from a mixed population of floods are used, and/or extreme floods generated by unusual events are inadequately represented. The flood-frequency approach also assumes that flood-generating processes do not change over time and that floods are random in time and space (Baker et al., 2002), even though it is known that flood frequencies are affected by, for example, climate variations (e.g. Ashmore and Church, 2001). Furthermore, landscape changes from geomorphic and/or geological processes can gradually alter channel or valley discharge capacities thereby increasing or decreasing the stage associated with a given magnitude of flow. The understanding of flood recurrence and changes in flood hazard can however be enhanced through geoscientific research that provides a long-term perspective on flood history and processes influencing flooding.

RED RIVER FLOODING GEOSCIENCE RESEARCH PROGRAM

Geoscientific research carried out since 1997 has addressed the nature of the largest known flood, in 1826, whether comparable large floods have occurred in recent centuries, and how geomorphic, climatic, land use, and tectonic factors may be changing the flood hazard.

The record of Red River floods is being enhanced through the study of tree rings (St. George and Nielsen, 2000; *in press*), floodplain lake cores (Medioli, 2001; 2003), floodplain deposits (Brooks, *in preparation*; Lian and Brooks, *in preparation*), archaeological sites (Kroker, 1997; 1998), and Lake Winnipeg cores presented here. Studies of geomorphic processes governing Red River evolution (Brooks et al., 2001; Brooks, submitted, a; b), landscape reconstructions (Hanuta, 1998), and valley gradient changes (Brooks et al., *in preparation*; Lewis and Thorleifson, *in preparation*) are addressing how the flood hazard may be changing.

Previous flood record

Previously, the timing and magnitude of Red River floods was only known from instrumental flood stage records and historical records. Instrumental flood stage records for the Red River Valley began in 1912, and since this time floods exceeding 2000 m^3/s have occurred in 1916, 1948, 1950, 1966, 1969, 1970, 1974, 1979, 1987, 1996, 1997 and 1999, and those exceeding 3000 m^3/s have occurred in 1950, 1979 and 1997. Archival records used to develop a flood stage record back to the early 19th century imply that floods exceeding 2000 m^3/s occurred in 1811, 1815, 1825, 1826, 1827, 1828, 1850, 1851, 1852, 1861, 1882 and 1904, while events exceeding 3000 m^3/s occurred in 1826, 1852 and 1861 (Rannie, 1998).

About half of the drainage area of the Red River (290,000 km^2) is the basin of the Assiniboine River (153,000 km^2), a major tributary that joins the Red River at Winnipeg, 65 km south of Lake Winnipeg. Large floods, with peak discharge greater than about 550 m^3/s, on the Assiniboine River occurred in 1882, 1904, 1916, 1922, 1923, 1974 and 1976 (Red River Basin Investigation, 1953; Rannie, 1998).

Tree-ring studies

Tree-ring studies (St. George and Nielsen, 2000; *in press*) have provided evidence for floods on the Red River predating the archival record. Prolonged inundation from high magnitude Red River floods, such as the 1950 flood or larger, appears to cause bur oak trees (*Quercus macrocarpa* Michx.) growing along the river to develop anatomically distinctive tree-rings, or 'flood rings', that can be used to identify Red River floods (St. George and Nielsen, 2000). This method was confirmed based on identification of five of the seven largest floods in the Lower Red River (LRR) basin during the last 200 years (1826, 1852, 1950, 1979, and 1997). Floods in 1861 and 1996 were not recorded by the tree rings. Additional floods in 1747 and 1762, which predate the archival record, were indicated by tree rings. The record for the Upper Red River (URR) basin identified floods at AD 1510, 1538, 1658, 1682, 1726, 1727, 1741, 1747 and 1762 (St. George and Nielsen, *in press*). Relative flood magnitudes were inferred on the basis of frequency of associated flood rings at a number of sites, as larger floods inundate more trees. The flood of 1826 was deemed the most severe flood to occur in at least the last 352 years. The magnitude of a flood identified at 1747 was found to be equivalent to that of the flood of 1852. Magnitudes of floods in 1762 and 1950 were inferred to be equivalent, as were floods in 1979 and 1997, from the tree-ring perspective. The LRR record contains three periods during which there is a grouping of Red River high-magnitude floods: the mid 1700s, the early to mid 1800s and the latter half of the 20th century. Tree-rings indicate that there was spring flooding along both the Red and Assiniboine rivers in AD 1826, 1538 and 1510.

In addition to providing dated paleoflood events, tree-ring research has also made possible inferences about hydroclimate. The tree-ring data indicates that the hydroclimate in southern Manitoba has been relatively stable over the last two hundred years, but prior to this, hydroclimate was more variable (St. George and Nielsen, 2002). Notably, conditions in the Red River basin were extremely dry between AD 1670 and 1775, with below normal precipitation occurring approximately two years out of three. The long-term hydroclimate record indicates that regional drought and flood planning based exclusively on 20th century measured records may under-estimate the worst-case scenarios.

Small lakes

The deposits of three small lakes on the Red River floodplain, Horseshoe Lake and Lake Louise, Manitoba, and Salt Lake, North Dakota, were cored and analyzed for a flood record (Medioli, 2001). Chronological and palynological data reveal a marked increase in sedimentation rates in all three lakes following the introduction of extensive agriculture. Detailed analysis of the texture, mineralogy and geochemistry has been completed, revealing significant changes in lake chemistry and biota attributed to the effects of agriculture, although no record of flooding was found (Medioli, 2003). Analysis of diatom and thecamoebian biota is underway. Key to this work is applying a biostratigraphic flood signature that has been defined using flood sediments sampled from the flood zones immediately following the 1997 and 1999 floods (Medioli and Brooks, *in press*).

Floodplain deposits

Floodplain alluvial deposits at several sites along the Red River were examined to determine if these sediments hold a record of flooding. The chronology of the sediments was established using radiocarbon dating of charcoal (Brooks, *in preparation*) and optical dating (Lian and Brooks, *in preparation*). Lateral and vertical sedimentation rates of the floodplain were determined (Brooks, *in preparation*). However, the sediments did not yield a flood record.

Reconnaissance stratigraphic and geochronological analyses of flood deposits exposed on the lower Red River floodplain were also carried out by E. Nielsen and G. Matile of the Manitoba Geological Survey (MGS). Selected alluvial sediment exposures examined during a reconnaissance survey in 1997 were logged in detail in August and September of 1998. These sediments are made up of couplets consisting of coarse silt or clayey silt overlain by finer textured clay or silty clay. The couplets were measured to test the hypothesis that these are individual flood deposits, each with a thickness proportional to the magnitude and/or duration of the associated flood. Detailed sedimentological observations, including measurements of rising flood and slackwater bed thickness, texture, nature of contacts, as well as evidence of slumping and channelling, were recorded at five sites on the lower floodplain in an area of what seems to be high recent overbank sedimentation rates, between Emerson and St. Jean Baptiste. The measured sections vary between 2.7 and 5.8 m in height and contain from 46 to over 155 flood couplets. Observations also were made at several sites between Emerson and Morris. It was unclear, however, if these deposits represent floods.

Age determinations in these riverbank alluvial sequences, therefore, are being undertaken by a combination of dendrochronology, Pb-210 and Cs-137 analysis, C-14 dating, macrofossil biostratigraphy, as well as analysis of 19th and 20th century artefacts found in many of the deposits. Dendrochronological analyses are being carried out on 16 *in situ* tree stumps rooted between 0.9 and 5.9 m depth in the flood deposits and 13 allochthonous logs recovered from depths between 0.2 and 5.0 m. Sediments at one site were sampled for Pb-210 and Cs-137 dating, and two sites were sampled for macrofossil analysis. Wood, bone, and charcoal samples were collected for radiocarbon dating from most of the sites. Buried bottles, which may be associated to a time period, were recovered at five sites.

Between Emerson and Morris, recently deposited sediments of variable thickness unconformably overlie older, slumped terrace deposits in most exposures. The older slumped terrace deposits, which are common and widespread, consist largely of homogeneous yellow silt and black topsoil whereas the overlying floodplain deposits comprise organic-rich brown to grey laminated silt and clay. The widespread presence in these deposits of both live and dead trees in growth position and with numerous adventitious roots indicates active and steady overbank sedimentation on the floodplain in recent decades. Only a few sites show evidence of significant sporadic sedimentation, as indicated by the position of adventitious roots on buried tree trunks. Furthermore, the presence of bottles and other refuse dating to the 1950s buried as much as 1-2 m below the surface, suggests that deposits that mantle the floodplain date to the late 19th and 20th centuries. At several sites, bison bones occur at the unconformity between the yellow silt and the overlying floodplain deposits, but nowhere have they been found above the contact. This further suggests that even the oldest riverbank floodplain deposits may not predate 1825 to 1850, the approximate date when bison became extinct in southern Manitoba. It therefore is unlikely that useful information will be obtained from these deposits.

Archaeological sites

Efforts were made to obtain information about past flooding from archaeological data obtained from fluvial sediments and cultural strata in Winnipeg (Kroker, 1997; 1998). While archaeologists routinely document stratigraphic profiles above the cultural stratum that is being investigated, these data seldom are interpreted in terms of geological or climatic events post-dating the cultural occupation. In areas that experience repeated sedimentation episodes, the cultural horizons may serve as temporal markers between succeeding depositional events, especially when there has been insufficient time elapsed for the formation of a soil horizon. In addition, the cultural identification of the occupants provides a broad temporal range for the occupation, while radiocarbon dates obtained from organic materials within the archaeological horizon can provide more exact dating of the previous flood episode.

Archaeological investigations at the junction of the Red and Assiniboine Rivers in particular have produced stratigraphic data that may be used to determine sedimentation and soil accretion regimes. The existing body of data was examined by Kroker (1997; 1998), in an attempt to delineate alluvial sedimentation and hence flood frequency for up to 6000 years ago, the oldest evidence of occupation. The excavations at Fort Gibraltar I (Kroker et al., 1990; 1991; 1992), occupied from AD 1810 to 1816, just north of the junction of the rivers, yielded profiles containing evidence of discrete strata presumably laid down by flooding after the destruction of the fort, including strata which can be chronologically linked to known floods. A 3-m stratigraphic profile obtained in 1997 includes at least ten discrete pre-fur trade cultural horizons, each of which contain culturally identifiable ceramics, indicating that the lowest horizon, at 3.05 m depth, post-dates AD 800. The uppermost 1.45 m is tentatively linked with a nearby archaeological horizon, ^{14}C-dated at 570 ± 80 years BP (ca AD 1400). This suggests that at least ten flood episodes occurred within the ~ 600-year span. Evidence obtained during the excavations of a campsite immediately adjacent to the north bank of the Assiniboine River indicated considerable sand deposition, characteristic of the Assiniboine sediment load, both prior to and after occupation, ^{14}C-dated at 2870 years BP. This suggests that the Assiniboine River was flowing in its present channel, at least intermittently, nearly three millennia ago.

1999 Lake Winnipeg coring

The coring in Lake Winnipeg, receiving basin of waters from the Red River, was designed to sample sites most likely to have recorded any influx of sediments from the Red River that may have occurred (Figure 1). In addition to recording gradual changes in Red River sediment transport, it was thought that flood events might be recognizable, due to unique properties allowing differentiation from other sediments in the lake, although it was unclear what attribute would best distinguish flood-related sediments. The cores therefore were thoroughly analyzed for chronology, as well as for a broad range of physical, chemical and biological properties to determine which, if any, would record a history of flooding. Data and inferences derived from these cores are presented in this Open File.

Red River geomorphology

To assess the relevance to the flood hazard of fluvial geomorphic changes, either erosion or aggradation, along the Red River valley, a borehole investigation was undertaken at two successive river meanders located near St. Jean Baptiste (Brooks et al., 2001). Boreholes were cored in two transects (99RR1 and 99RR3) on opposite sides of the valley bottom, with each transect consisting of five boreholes. The boreholes were sited to follow the path of lateral migration of the channel, as revealed by a ridge and swale pattern on the floodplain.

The floodplain alluvium in the cores consists mostly of silt, ranging in thickness from ~ 15 to 22 m, reflecting the fine grained suspended load typical of the river, although some sand beds were encountered (Brooks, submitted, a). Sedimentary structures consist of beds of massive silt and deformed and disrupted silt, interpreted as slumps, as well as minor deposits of sand and silt beds and local deposits of sand and pea gravel. The sequence consists of overbank deposits, overlying oblique accretion deposits and oblique accretion and/or channel deposits. Large-scale mass movements along the convex banks are considered the cause of deformed beds. The banks along both straight and curved channel reaches experience mass movements in the form of a very slow slides or slumps. Fluvial erosion is actively occurring along the toe of such banks. Net sedimentation along many river meanders is occurring along the downstream extension of the concave bank well beyond the meander apex rather than at a point bar deposit situated at the apex itself. The lack of sand-sized aggregates in the alluvium is attributed to post-depositional disintegration and/or coalescence by compaction. Overall, the Red River represents a style of low-energy, silt alluvial system that is poorly documented in the fluvial geomorphology and sedimentology literature.

Radiocarbon dates in the cores provided the age of the encapsulating lateral accretion deposits in the lower portion of the alluvium, allowing reconstruction of past positions of the river channel over the past 8000 years (Brooks, submitted, b). These reconstructions reveal that there has been appreciable lateral channel migration since 1000 years BP, when the rate of channel migration averaged about 0.04 $m.a^{-1}$ at both meanders (Brooks, submitted, b). Two meanders near St. Jean Baptiste have extended outwards and rotated down-valley since 8000 years BP in a single phase of lateral channel migration. Migration at both meanders since 1000 yr BP has averaged about 0.04 $m.a^{-1}$. The lateral incision of the channel is estimated to have averaged between 0.6 and 0.8 $m.kyr^{-1}$ since 8000 yr BP. The cross-sectional area of the valley bottom increased by about 2% and 0.7% at the two meanders between 1000 and 0 yr BP. Overall, changes to the valley cross-section area caused by the lateral migration of the river have produced negligible variations to the flood hazard on the clay plain since 1000 yr BP.

Landscape reconstruction

Human-induced modification of the landscape since the 1870's may have had a significant impact on the frequency, magnitude, and character of flooding. In order to obtain a baseline for assessment of landscape modification, the state of the flooded area in the 1870's was mapped from archival sources (Hanuta, 1998).

The Department of the Interior, Dominion Land Survey township maps from the 1870's were consulted and analyzed to produce a classification of the landscape before extensive settlement occurred. The original historical environmental information and classification found in these maps was used to generate a classification scheme of land cover. Content Analysis, the derivation of quantitative information from textual material, was used to review and assess written descriptions of landscape found on township plans. Landscape areas were classified into four categories, including prairie, woodland, scrub and wetland. Much information existed among the words used to describe any particular landscape or phenomena. This consistency appeared over all the townships in the study area and from surveyor to surveyor. Of the four categories, the prairie landscape category was the most common, especially in Ranges 1 and 2 West. Progressing eastward, more vegetation diversity appears as written descriptions of other vegetation show an increase in frequency. After prairie, wetland regions were the next most prevalent surface feature described. The research demonstrated that, although wetlands previously were more extensive, the dominant pre-1870's land cover was grassland.

Changes in valley gradients

Post-glacial crustal rebound resulting from the isostatic depression of the land surface by the Laurentide Ice Sheet during the late Pleistocene has affected the regional landscape of the Manitoba. This is readily exemplified by the differential tilting up to the north-northeast of Lake Agassiz shorelines in Manitoba, eastern North Dakota, and western Minnesota (Teller and Thorleifson, 1983), and by contemporary crustal tilting indicated by geodetic data and lake gauge (Lambert et al., 1998; Tackman et al., 1999). Furthermore, post-glacial uplift has caused the north end of the Lake Winnipeg basin to rise relative to the south, causing a gradual rise of lake levels that continues at present (Lewis et al., 2000; 2001). The barrier island system at the south end of Lake Winnipeg is transgressing southward (Nielsen, 2000) under the influence of waves acting on a long-term rising water surface resulting from this glacio-isostatic tilting.

The longitudinal profile of the Red River therefore was modeled at 500-year intervals to reconstruct the loss in river gradient resulting from differential uplift and determine what influence this may have had on flooding (Lewis and Thorleifson, *in preparation*). Preliminary modeling indicates that the Red River in southern Manitoba has lost about half of gradient since 8000 yr BP. The Canadian Hydraulic Centre, National Research Council, has modeled the magnitude of the 1997 flood under different scenarios of gradient to determine how the extent and depth of flooding has changed over time due to the differential uplift. These results will be summarized by Brooks et al. (*in preparation*).

LAKE WINNIPEG

Lake Winnipeg is the eleventh largest lake in the world with a surface area of 24,000 km^2. Its catchment area encompasses 983,000 km^2, extending from the Rocky Mountains to near Lake Superior, encompassing the basins of the Winnipeg, Saskatchewan, Red, Dauphin and numerous smaller rivers (Figure 1). Outflow from the lake is north to Hudson Bay, through the Nelson River.

The shores of the lake lie within four physiographic domains, with the eastern shore occupied by the transitional zone of the Canadian Shield, the western shore by the Interlake-Westlake plain of the Manitoba lowlands, the southern tip by the Red River plain, and the northern tip by the Upper Nelson plain. The eastern shore has relief that is rolling to undulating, with extensive areas of peat, swamp and muskeg overlying glacial drift and bedrock. The western shore has gentle relief, consisting of a cover of calcareous till, overlain in some areas by lacustrine clays. The eastern and western shores are eroded by waves during the annual ice-free season. Much of the southern shore is flat to gently undulating with relief of less than 3 m, consisting of lacustrine clay and alluvial deposits. Barrier sand ridges are built by waves along the southern shore between distributary outflow channels of the Red River and local streams. The northern shore is flat to gently undulating and is comprised of lacustrine clay and alluvial deposits. The lake straddles the contact between Paleozoic carbonate bedrock to the west and Precambrian igneous and metamorphic rocks of the Canadian Shield to the east.

The lake consists of a north and south basin that are separated by a narrow passage. The south basin is approximately 90 km by 40 km and has a low-relief bathymetry with a maximum depth of about 12 m and an average depth of 9 m. The Red and Winnipeg rivers are the largest to flow into the south basin. The continental climate of the Lake Winnipeg area is characterized by long, cold winters and relatively short, cool summers, and the mean annual temperature of the region, recorded at Gimli, is +1.4°C. However, Lake Winnipeg modifies temperatures such that the south end has both warmer winter and summer temperatures than the north end. The mean annual precipitation is 50.8 cm, and is greater at the south end than the north end. The lake is ice free from early May to late November, although this too varies (Ice Thickness Climatology, 1992) and ice cover from November to May is consistently thick and continuous. The lake waters are poorly stratified to unstratified and during the summer months water temperatures range from +17°C in the north basin to +19.5°C in the south basin (Todd, 1996), hence bottom sediment temperatures are equally warm in mid-summer. Commonly the lake-bottom is disturbed by ice scour related to wind-driven pressure ridges (Todd et al., 1998).

Lewis and Todd (1996) and Todd et al. (1998) summarized the lithology and seismostratigraphy of the sediments underlying Lake Winnipeg. A lower unit, overlying till or bedrock, was attributed to glaciolacustrine sedimentation in glacial Lake Agassiz. Unconformably overlying Lake Agassiz sediments is the 1-7 m thick post-glacial deposit of Lake Winnipeg. In the south basin, this sedimentation began about 4000 yrs BP as the lake expanded in response to climate change and post-glacial uplift (Lewis et al., 2000; 2001).

Phytoplankton diversity and abundance in Lake Winnipeg vary spatially and temporally, and are controlled largely by climate (temperature and light) and drainage (nutrient inputs and major ion composition) (Kling, 1996; 1998; 2002). Species changes, particularly in nitrogen-fixing blue green akinetes that exhibit a shift to Stephanodiscus *niagarae*, and diatoms that exhibit a shift to Aulacoseira *granulata* and Aulacoseira *ambigua*, near the top of a sediment core indicate increased nutrient influx, beginning about 1900. It is believed that the recent nutrient influx to Lake Winnipeg is the result of P loading from municipal and agricultural sources, increased P loading by a decade of relatively high runoff, increased transparency brought about by retention of turbidity behind a hydro dam at Grand Rapids, and/or increased P retention/recycling associated with manipulation of lake storage and discharge for the production of hydroelectric power (Stainton et al., 2002, a). Monitoring of riverine inputs to the lake indicates that most P is delivered by the Red River, with most of it derived from the city of Winnipeg and agricultural sources (Stainton and McCullough, 2002). Turbidity is the limiting control on productivity in the south basin, whereas nitrogen is the limiting control in the north basin (Stainton et al., 2002, b).

Lake Winnipeg supports a commercial fishery, is a major destination for recreation, and lake levels are regulated to optimize hydroelectric power generation on the Nelson River.

Sediment budget

Penner and Swedlo (1974) estimated that the Red River contributes an estimated 83 % (2.3 M tonnes/yr) of the sediment input to the south basin by weight, with shoreline erosion accounting for the remaining 17 % of the sediment (0.51 M tonnes/yr), determined from historic rates of shoreline erosion and suspended sediment data. Contributions from the Winnipeg River are considered minimal, as it passes through several lakes along its course, removing much of the suspended sediment load prior to entering Lake Winnipeg. Whereas > 90 % of Red River suspended sediments consist of silt and clay (Glavic et al., 1988), the sediment derived from shoreline erosion of Lake Winnipeg consists of about 55 % clay and silt and 45 % sand and gravel (Penner and Swedlo, 1974).

Kushnir (1971) estimated sediment accumulation rates in the south basin to be 0.3 - 0.8 mm/yr, based on Red River suspended sediment data from 1963-1967. In this calculation, the contribution of other inputs is considered equal to sediment outflow from the south basin through the Narrows and that deposition occurred only within the 8-m depth contour (2590 km^2). The 8-m contour was defined as the basin of fine sediment accumulation, based on grain size, qualitative interpretation of sonar penetration into the sediments, and textural stratigraphy of the sediments (Brunskill and Graham, 1979). Brunskill and Graham (1979) estimated rates to be 0.5 – 0.9 mm/yr, using Red River suspended sediment data from 1969-1973 and making the same assumptions as Kushnir (1971). Vance and Telka (1998) confirmed sedimentation rates of about 1 mm/yr for the past 4000 years, based on sediment thickness above a radiocarbon-dated sample from sediment just above the Lake Agassiz/Lake Winnipeg sequence boundary in the center of the south basin. The estimate by Vance and Telka (1998) is slightly greater than those of Brunskill and Graham (1979) and Kushnir (1971) as it represents the amount of sediment deposited from all sources, not just from the Red River. Lockhart et al. (2000) found accumulation rates to be 3.0 mm/yr for the uppermost 25 cm of cores collected in 1996, although long-term rates of 1 mm/yr imply that the deeper sediments have been compacted.

A sedimentation rate of 1 mm/yr can be explained by an influx of 4.4 M tonnes of sediment annually, assuming that 1714 kg equals 1 cubic meter of sediment (Ward, 1926) and that deposition occurs within the 8-m depth contour. About 1.9 M tonnes enters annually from the Red River and 0.5 M tonnes/yr is attributed to shoreline erosion (Penner and Swedlo, 1974). About 2.0 M tonnes/yr of sediment is unaccounted for, some of which may be attributed to assumptions and errors in calculations.

LAKE WINNIPEG PROJECT

The Lake Winnipeg project was launched by the Geological Survey of Canada and the Manitoba Geological Survey in 1994 to support management of issues such as shoreline erosion. A four-week cruise of the Canadian Coast Guard Ship (CCGS) *Namao* in 1994 was followed by a similar effort in 1996, shoreline investigations in 1997, the one-day cruise in 1999 described here, as well as ongoing uplift measurement and small vessel work.

The 1994 cruise began with a northbound geophysical survey, followed by a southbound coring phase. Limnological and environmental sampling were undertaken concurrently in cooperation with the Freshwater Institute (FWI), Department of Fisheries and Oceans (DFO), and a grid of bottom sediment samples, coupled with biological and water sampling, was carried out from the ship's launch during the southbound coring phase. A two-week survey of the Lake Winnipeg shoreline followed. For the geophysical survey, east-west transects, with south-north tie lines, were run in the south and north basins and the connecting narrows. Over 500 km of geophysical track lines were obtained using low frequency air gun seismic, high frequency seismic and sidescan sonar. Ground penetrating radar and marine magnetometry were also tested, but few useful results were obtained. Coring was conducted to sample the sediments and to verify stratigraphy and features identified in the geophysical records. A total of 60 m of core was obtained, using both gravity and piston corers, from thirteen sites, with core lengths ranging from 2 to 8 m. Box cores were obtained at 10 sites to obtain a high-resolution record of recent sedimentation.

For the 1996 cruise, emphasis was placed on confirmation and dating of the southward migration of the lake, and scouring of the lake bottom by ice. This cruise included a geophysical survey of ice scour features and lake bottom stratigraphy, as well as core collection. Approximately 238 km of survey lines were completed using low frequency seismic, high frequency seismic and sidescan sonar. The use of dual frequency sidescan sonar permitted distinction of recent from buried ice-scour features. Approximately 135 m of core was obtained from 22 sites using a gravity corer and a split piston corer. Limnological and biological sampling was again carried out in 1996.

The 1994 Lake Winnipeg survey, the first comprehensive survey of the Lake Winnipeg basin since 1969, produced many fundamental insights into the structure and evolution of the basin. The survey is fully documented in Geological Survey of Canada Open File report 3113 (Todd et al., 1996). The 1996 survey is documented in Geological Survey of Canada Open File report 3470 (Todd et al., 2000).

Seismic and sidescan sonar records provided information on the geometry of the bedrock surface, of the distribution, thickness and structure of sediments infilling the Lake Winnipeg basin, and of the nature of lake bottom morphological features (Todd and Lewis, 1996; Todd et al., 1998). Based on low and high frequency seismic records, and on the analysis of long cores obtained in 1994 and 1996, a detailed interpretation of the seismostratigraphy and lithostratigraphy of sediments in Lake Winnipeg has been conducted (Lewis and Todd, 1996). Sidescan sonar and high frequency seismic records obtained in 1994 and 1996 permitted delineation of numerous NNW-SSE trending linear ice scours. These features are thought to result from scouring by keels of ice pressure ridges that have moved under the influence of wind stress and ice pressure during the spring break-up season.

In summary, geoscience surveys in Lake Winnipeg clarified processes at work in the basin, and indicated that, although ice scour is common throughout much of the basin, there are several areas free of ice scour. Sidescan sonar records were studied in order to select scour-free sites for coring in 1999. The results also indicate that fine-grained sediments are accumulating in the central south basin at a rate of about one metre per millennium, providing a suitable resolution for examining paleoenvironmental change.

PALEOLIMNOLOGICAL METHODS

The cores from Lake Winnipeg were analyzed using current methods in paleolimnology. The field of paleolimnology, the multidisciplinary study of lake basins for the purpose of interpreting past conditions and processes, has made significant contributions to the development of paleoclimate and paleoenvironmental records. Recent years have seen a rapid advance in paleolimnological techniques, documented in a series of monographs by Smol and Last (2001), built on the foundation of many years of previous study (Kummel and Raup, 1965; Bouma, 1969; Carver, 1971; Berglund, 1986; Gray, 1988; Tucker, 1988; Warner, 1990; Rutter and Catto, 1995). This open file is a contribution to the growing field of paleolimnology, as it (i) takes a multidisciplinary approach, integrating data from a variety of chronological, physical, chemical, and biological analyses, (ii) uses current methods of lake-floor imaging, coring, and physical property and paleomagnetic analysis to attempt to obtain an undisturbed, high resolution record, and (iii) provides paleoenvironmental information on flooding over the past millennium, and on nutrient influx, and heavy metal contamination in the past century.

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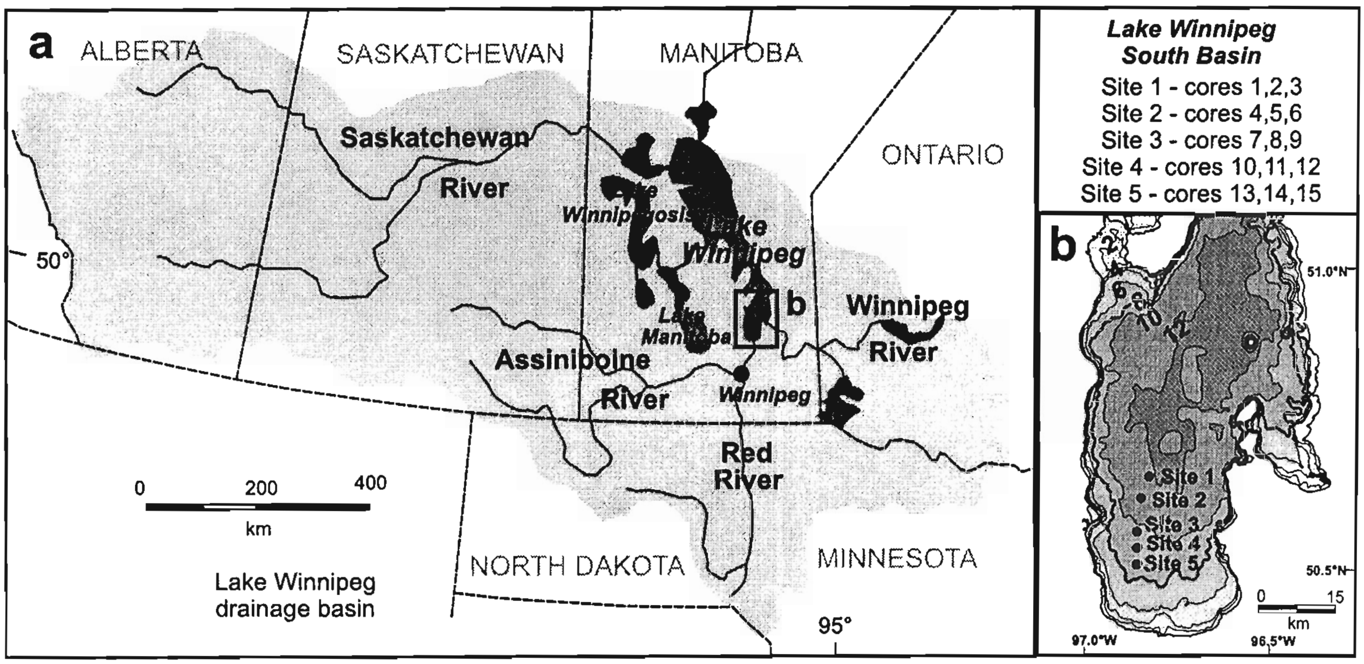

Figure 1. (a) Lake Winnipeg drainage basin, and (b) location of cores collected from the south basin in 1999. Bathymetic contours are in meters.

3. Cruise report – *Namao* 99-900

3. Cruise report of the 1999 Lake Winnipeg Project: *Namao* 99-900

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ABSTRACT

In August 1999 the Canadian Coast Guard Ship (CCGS) *Namao* was utilized to carry out a one-day cruise on the south basin of Lake Winnipeg. The sole objective was to obtain 15 gravity cores from 5 sites, to be analyzed for chronology and a range of compositional parameters to address the history and controls of flooding on the Red River. The cruise lasted approximately 7.5 hours, during which time calm weather persisted. The ship's echo sounder and chart recorder were used to test for the presence of ice scour that may have occurred since the sidescan records used to select coring sites were obtained in 1994. Real-time differential GPS navigation was used to record the time and position of the ship's path. The cores ranged in length from 107 cm to 170 cm.

INTRODUCTION

[*]The Red River flood of 1997 was a major disaster that drove 103,000 people from their homes. Much is being done, however, to reduce comparable damage and disruption in the future through enhanced dikes and diversions, as well as revised land use and water management practices. The design of these works requires an optimal understanding of the risk. Research therefore has addressed the nature of the largest known flood, in 1826, whether comparable large floods have occurred in recent centuries, and how geomorphic, climatic, land use, and tectonic factors may be changing the flood hazard. These issues are being addressed by examining the geomorphic processes governing evolution of the Red River, archival records of flood history, floodplain stratigraphic records, tree-ring records, changes in valley gradients, and by examining the stratigraphy of Lake Winnipeg sediments (Thorleifson et al., 1998). The coring in Lake Winnipeg, receiving basin of waters from the Red River, was designed to sample sites most likely to have recorded the accumulated influx of sediments from the Red River during the last millennium. In addition to recording gradual changes in Red River sediment transport, it was thought that flood events might be recognizable. The cores therefore were thoroughly analyzed for chronology, as well as for a broad range of physical, chemical and biological properties to determine which, if any, would record a history of flooding.

[*] Italicized text is repeated in each chapter

CRUISE OBJECTIVE

The objective of the 1999 cruise of the Canadian Coast Guard Ship (CCGS) *Namao*, designated Geological Survey of Canada (GSC) cruise 99-900, was to obtain 15 undisturbed sediment cores, each about 1.5 m long, from 5 sites in the south basin of Lake Winnipeg. Subsequent analyses were planned to determine if the cores would reveal information on the history and controls on the flood hazard of the Red River.

TARGET SELECTION

Selection of 5 sampling sites (Figure 1) in the south basin of Lake Winnipeg was based on proximity to the Red River mouth and on the absence of ice scour evidence on sidescan sonar records previously obtained on the 94-900 *Namao* cruise (Todd et al., 1998, a; McKinnon et al., 2000). As movement by winter pressure-ridge ice keels can displace and mix sediment, it was important to avoid coring in ice-scoured sediment. Prior to the 1999 cruise, sidescan sonar records collected during an earlier cruise (1994) were inspected and target sites were set to positions where the lake bottom showed no evidence of ice scouring (Todd et al., 1998, a; McKinnon et al., 2000). To avoid the possibility of coring at a site where scouring had occurred since 1994, an onboard echo sounder was used to test for evidence of recent ice scour. A list of potential coring sites (Table 1) was compiled from the southernmost sidescan lines nearest the mouth of the Red River, as well as previous coring sites, all of which were deemed to be undisturbed during the 1994 and 1996 cruises. Fifteen cores were to be collected, to permit core-to-core correlation, to ensure there would be sufficient material for the planned analyses, and to permit cores to be chosen on the basis of quality determined by physical property and paleomagnetic analysis.

The southernmost site was located 13 km from the river mouth, as sites farther south were completely disturbed by ice scour. The bottom sediments of Lake Winnipeg exhibit linear to curvilinear scours (Figure 2), up to one metre deep, commonly several kilometres in length and 200 metres wide, flanked by sediment deposits averaging 0.5 m in thickness (Todd et al., 1998, a). The formation of these features is attributed to the compression by wind of lake-ice slabs to form pressure ridges with relatively deep keels, which had scoured the lake bottom. The orientation of most scours is NNW-SSE (Figures 3 and 4), a direction that correlates with prevailing winds in the region for the late winter and spring (McKinnon, 1996).

NARRATIVE ACCOUNT OF CRUISE

The CCGS *Namao* (Figure 5) departed from Gimli at 0837 hours local time, on August 24, 1999 (Day 236) (Figure 6). The onboard scientific personnel consisted of Mike Lewis, Chief Scientist, and Bob Murphy, coring technician, from GSC Atlantic, and Matt Pyne, navigation technician, from GSC Ottawa. The dimensions of the ship and the layout of the scientific equipment are illustrated in Figure 7. Weather conditions remained calm throughout the day. From Gimli, the ship travelled in a northeasterly direction towards the first targeted site. The Global Positioning System (GPS) navigation logging was activated at the beginning of the cruise. GPS gear was reconfigured between 0854 and 0934 hours, which resulted in a gap in the record. The sites typically were approached from two different bearings in a figure-eight pattern (Figures 8 to 17), and the ship's echo sounder (Raytheon Survey Fathometer) was activated to confirm the absence of ice scour. The *Namao* arrived at the first site at 1027 hours. Three cores were collected in sequence, separated by several tens of meters, resulting from the gradual drift of the ship. The gravity corer was lowered into the water on the port side of the ship from the ship's crane. The corer was raised from the sediments using the crane and the core brought on board to be packaged and stored. After coring was complete at site 1, the ship proceeded in a southerly direction, as all of the targets were located on a N-S line. At each of the four other sites the approach and coring procedures were similar to those of site 1, except that for the latter sites the anchor was dropped prior to coring in order to minimize drift between cores at a single site. The *Namao* arrived at sites 2 (Figures 10 and 11), 3 (Figures 12 and 13), 4 (Figures 14 and 15) and 5 (Figures 16 and 17) at 1127, 1248, 1349, and 1448 hours, respectively. GPS gear was refitted with a battery between 1157 and 1202 hours, resulting in a brief recording lapse. Following coring at site 5, the *Namao* travelled in a northwesterly direction, reaching Gimli at 1557 hours.

NAVIGATION AND POSITIONING

The location of the ship was determined from the satellite-referenced GPS in differential mode. Two positioning systems were used. The first system (GPS 1), leased from Cansel Survey Equipment in Winnipeg, was a Trimble ProXR used to navigate the *Namao* to previously selected targets. This system was real-time corrected to a base station in Winnipeg by satellite. During lowering of the gravity core a waypoint was recorded, in addition to the time of lowering and the bearing of the *Namao*. To account for the difference in position between the GPS1 antenna and the end of the *Namao* boom, a correction was applied to the measured location to yield the coring location. The second system (GPS2) was a Trimble ProXR, which was used to record the ship's path. Data (UTC time, latitude and longitude) were recorded every 10 seconds. The navigation data was differentially corrected using carrier phase data collected from a base station set up in Gimli. Positional accuracy is estimated to be within one meter.

SITE SURVEYS

Target selection was based on the absence of evidence of ice scour on sidescan sonar records previously obtained on the 94-900 *Namao* cruise (Todd et al., 1998, a). The ship's echo sounder (Raytheon Survey Fathometer) was used to test for the presence of scours that may have occurred since the sidescan recordings were obtained (Figure 18). Targets were typically approached at two different bearings in a figure-eight pattern over the target site. The sites did not show evidence of ice scour occurrence since the 1994 cruise, with the exception of site 5, which exhibited scours at the ends of the survey lines (Figure 18).

CORING

Three cores were obtained at each of the five targeted sites. As a coring target was approached, and if the site appeared unaffected by ice scour, the *Namao* typically was anchored and coring commenced on the port side of the ship. While swing anchored, the ship would pivot slightly, thus providing a separation between the locations of the three cores at each site. At site 1, the anchor was not lowered, so the separation between the three cores was greater than at the ensuing sites.

The cores were obtained using a gravity corer, which is preferable to a marine piston corer for cores less than 2 m long, as the amount of disturbance and shortening of the cored sediments is minimized by this method. The gravity corer consisted of a 100 kg weightstand over a 2 m steel pipe with a 10 cm diameter plastic liner tube (Figure 19). The corer was lifted from the ship and lowered into the lakebed using a crane attached to the ship. A steel collar of about 30 cm diameter was attached below the weightstand of the corer to prevent the corer from penetrating too far into the soft lake-bottom sediments. A one-way valve at the top of the coring pipe allowed water to exit during sediment penetration, but closed and retained the sediment core in the core pipe during its withdrawal from the lakebed and recovery to the ship's deck. The cores ranged in length from 107 cm to 170 cm, with an average of 156 cm (Table 2). At all sites, the soft muddy sediment allowed the corer to sink further without sampling the deeper sediment, up to 231 cm as measured on the weightstand after recovery (Table 2). Most cores were recovered with a slightly tilted upper surface, suggesting a small amount of surface mud had entered the core pipe through the open valve as the corer sank into the mud. The water depth at the coring location was also recorded (Table 2).

The cores were sealed and labelled aboard the ship, and upon completion of the cruise were transported to cold storage in Gimli, Manitoba, on the evening of August 24. Subsequently, the cores were transported by refrigerated truck to the GSC Sample and Core Repository in Dartmouth, N.S. During transport and storage, the cores were maintained upright in their original orientation. A temperature-monitoring device attached to the core bundle during transport showed that the ambient air temperature was held between 0.7°C and 10°C August 25-27, and between 13°C and 19°C August 28-30. While at the Sample and Core Repository, the cores have been maintained at a constant temperature of 4°C to 9°C, except when removed for splitting, logging and subsampling.

SELECTION AND COORDINATION OF ANALYSES

Selection of cores for various analyses is summarized in Table 3. All 15 whole cores were analyzed for paleomagnetic and physical properties at the laboratory of Professor J.W. King at the University of Rhode Island (URI), to assess core integrity, and to determine the sedimentation rate, which dictates the resolution of the record. Cores 3, 4, 8, 11, 13 and 14 were deemed to be of higher quality according to the paleomagnetic record, indicating intact and continuous paleomagnetic stratigraphy, while cores 1, 2, 6, 9, 12 and 15 were deemed to be of a somewhat lower quality due perhaps to factors such as inclined penetration during coring. On this basis, the high quality cores were selected and split longitudinally at URI where digital images were obtained. The more northern sites (sites 1, 2 and 3) were determined from paleomagnetic records to have a higher sedimentation rate, hence a higher resolution for detecting environmental change. Therefore, cores 3, 4 and 8 were selected as the most promising cores for detailed analyses and, after being transported to GSC Atlantic, were sliced into 1-cm subsamples. Subsequently, textural and inorganic geochemical (elemental) analyses were conducted on cores 3, 4 and 8, while Cs-137, Pb-210, and Rock-Eval organic analyses were performed only on cores 4 and 8. A complete palynological analysis was performed on core 8, and a partial analysis on cores 3 (20-35 cm) and 4 (top 45 cm). Carbon and nitrogen elemental and isotopic analyses were performed on core 8 only. Because a large amount of material was required for macrofossil recovery in these fossil-poor sediments, nearby cores (cores 5, 7 and 9) were selected for this purpose. Macrofossil samples for radiocarbon dating were eventually obtained from core 9.

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Todd, B.J., Forbes, D.L., Lewis, C.F.M., Matile, G.L.D., Nielsen, E. and Thorleifson, L.H.
1998b. Geology of Lake Winnipeg: highlights of the Lake Winnipeg Project 1994-1996; Geological Survey of Canada Open File Report 3434.

Table 1. Potential coring targets identified as lacking evidence of ice scour

Target	Line	Day	Time	To	Offset (m)	Correction (m)	Lat	Long	Lat_{corr}	$Long_{corr}$
1655	SB3	220	1655	Port	0-45	23 mW	50.516659	-96.8333	50.516659	-96.833622
1725	SB3	220	1725	Port	0-35	18 mW	50.54446	-96.8333	50.544460	-96.833552
1740	SB3	220	1740	Stbd	0-100	50 mE	50.558331	-96.8332	50.558331	-96.832494
1745	SB3	220	1745	Stbd	0-45	22 mE	50.563042	-96.8332	50.563042	-96.832889
1755	SB3	220	1755	Both	S0-60P0-100				50.572350	-96.833199
1820	SB3	220	1820	Both	S&P30-100				50.587799	-96.833199
1905	SB3	220	1905	Both	0-100				50.628551	-96.823303
1929	SB3	220	1929	Both	0-100				50.649601	-96.809303
1945	SB3	220	1945	Both	0-100				50.663502	-96.800102
1859	SB12	222	1859	Both	S0-50P0-100				50.523571	-96.674103
113a	SB6	223	2138						51.401500	-96.625500
BC114	SB5	222	1814						50.979000	-96.656500
BC116	SB3	220	1946						50.664333	-96.799667
BC117	SB4	221	1619						50.833333	-96.820000
BC123	SB3	220	1723						50.541500	-96.833167
GC115	SB5	222	1733						50.946000	-96.681667
GC119	SB4	221	2008						50.803167	-96.530167
PC120	SB4	221	1952						50.815167	-96.545000
GC121	SB4	221	1619						50.833333	-96.820000
GC122	SB3	220	1937						50.656500	-96.804667
PC215	SB15	227	1946						51.375000	-96.571667
PC216	SB15	227	1753						51.285000	-96.630000
PC217	SB15	227	1502						51.133333	-96.585000
PC218	Site	242	1608						50.943333	-96.681667
PC219	Site	242	1610						50.943333	-96.683333
PC220	Site	242	1641						50.946667	-96.681667
PC221	SB14	226	1829						50.935000	-96.616667
PC222	SB14	226	1710						50.935000	-96.736667
PC223	SB3	220	1937						50.656667	-96.805000
PC224	SB1	216	1930						50.550000	-96.786667

Table 2. Locations and lengths of cores collected on the 99-900 *Namao* cruise

Target No.	Site No.	Core No.	Latitude N	Longitude W	Water depth (m)	Core length (cm)	Penetration (cm)*
1945	1	1	50.663899	-96.801025	9.5	156	231
1945	1	2	50.664570	-96.801918	9.5	146	231
1945	1	3	50.665972	-96.802943	9.5	149	211
1905	2	4	50.628541	-96.823353	9.2	166	208
1905	2	5	50.628552	-96.823225	9.2	170	214
1905	2	6	50.628549	-96.823236	9.2	168	215
1755	3	7	50.572358	-96.833346	8.4	168	231
1755	3	8	50.572385	-96.833411	8.4	164	231
1755	3	9	50.572386	-96.833416	8.4	150	231
1725	4	10	50.544602	-96.834036	8.0	165	231
1725	4	11	50.544585	-96.834079	8.0	150	221
1725	4	12	50.544592	-96.834062	8.0	107	231
1655	5	13	50.516815	-96.833546	7.6	160	231
1655	5	14	50.517033	-96.833607	7.6	159	231
1655	5	15	50.517005	-96.833638	7.6	160	231

* Apparent penetration into lakebed indicated by uppermost sediment adhering to corer

Table 3. Selection criteria, processing and analyses performed on Lake Winnipeg 99-900 cores

	Core No.														
	1	2	[1]3	[1]4	5	6	7	[1]8	9	10	11	12	13	14	15
Selection criteria															
Optimal paleomagnetic record			X	X				X			X		X	X	
Suspect paleomagnetic record	X	X				X			X			X			X
Higher sedimentation rate	X	X	X	X	X	X	X	X	X						
Processing															
Split			X	X				X	X		X		X	X	
Sliced at 1 cm			X	X				X							
Sliced at 5 cm					X		X		X						
Analyses															
Paleomagnetic analysis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Physical property analysis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Digital images			X	X				X	X		X		X	X	
Textural analysis			X	X				X							
Cs-137 and Pb-210 analyses				X				X							
Elemental analysis			X	X				X							
Rock-Eval anlysis				X				X							
Palynological analysis			[2]X	[2]X				X							
C/N, $\delta^{13}C$ and $\delta^{15}N$ analyses								X							
Macrofossil analysis					X		X		X						
Radiocarbon analysis									X						

[1]Primary cores

[2]Partial core only (20-35 cm for core 3, 0-45 cm for core 4)

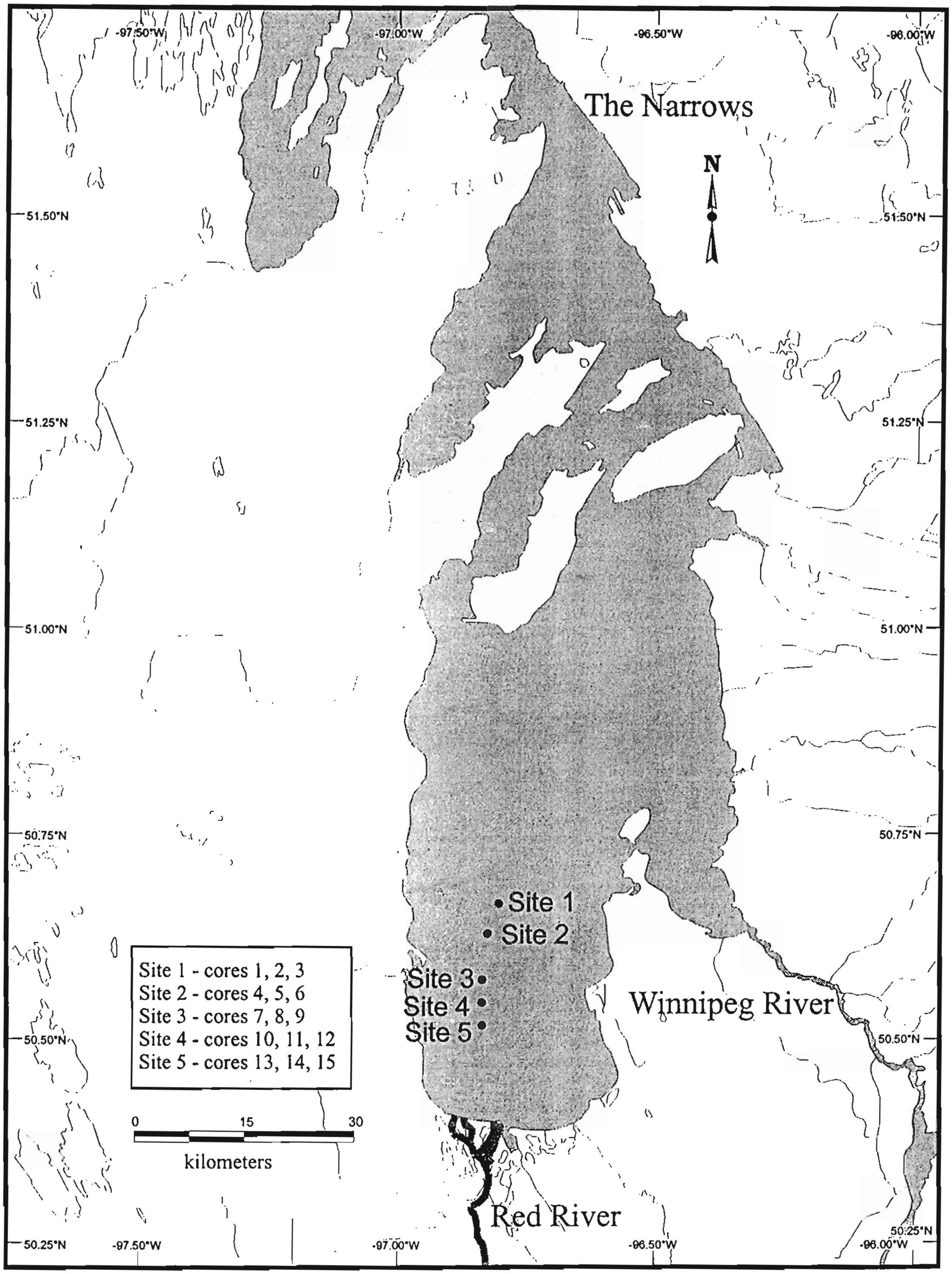


Figure 1. Map of southern Lake Winnipeg showing locations of coring sites

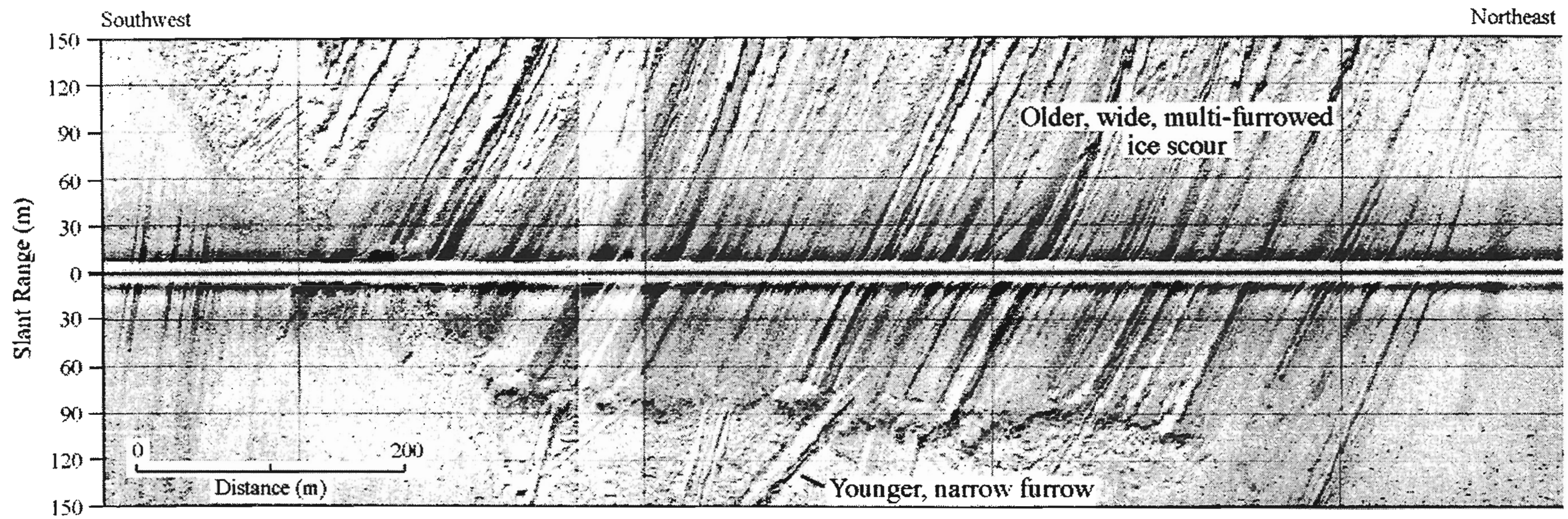


Figure 2. Example of ice scour in the south basin of Lake Winnipeg, shown on a 330 KHz sidescan sonar image (from Todd et al., 1998b)

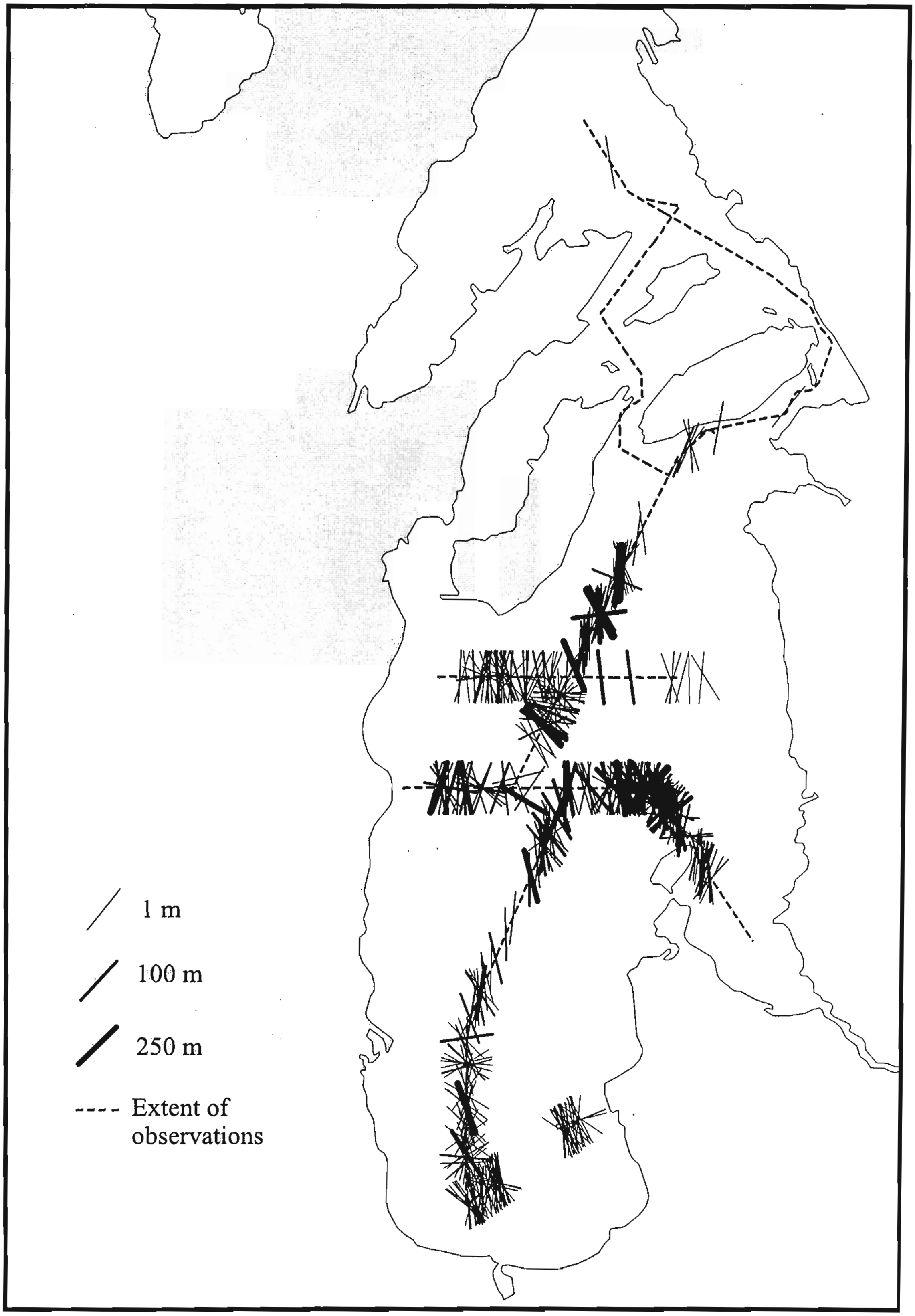


Figure 3. Orientation and width of ice scour features in the south basin of Lake Winnipeg (from McKinnon et al., 2000)

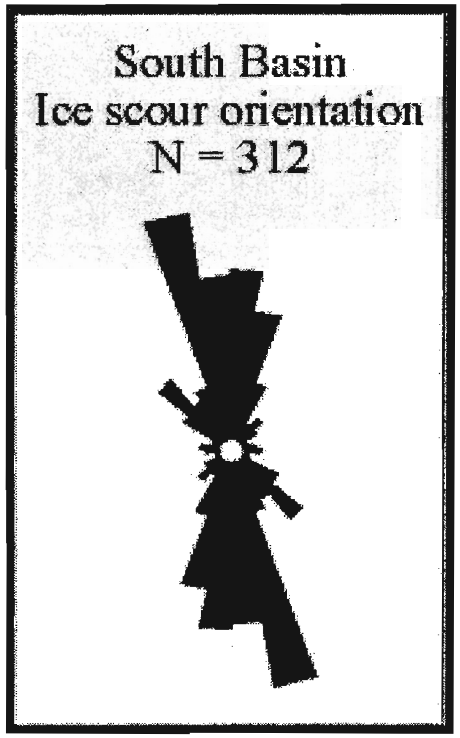
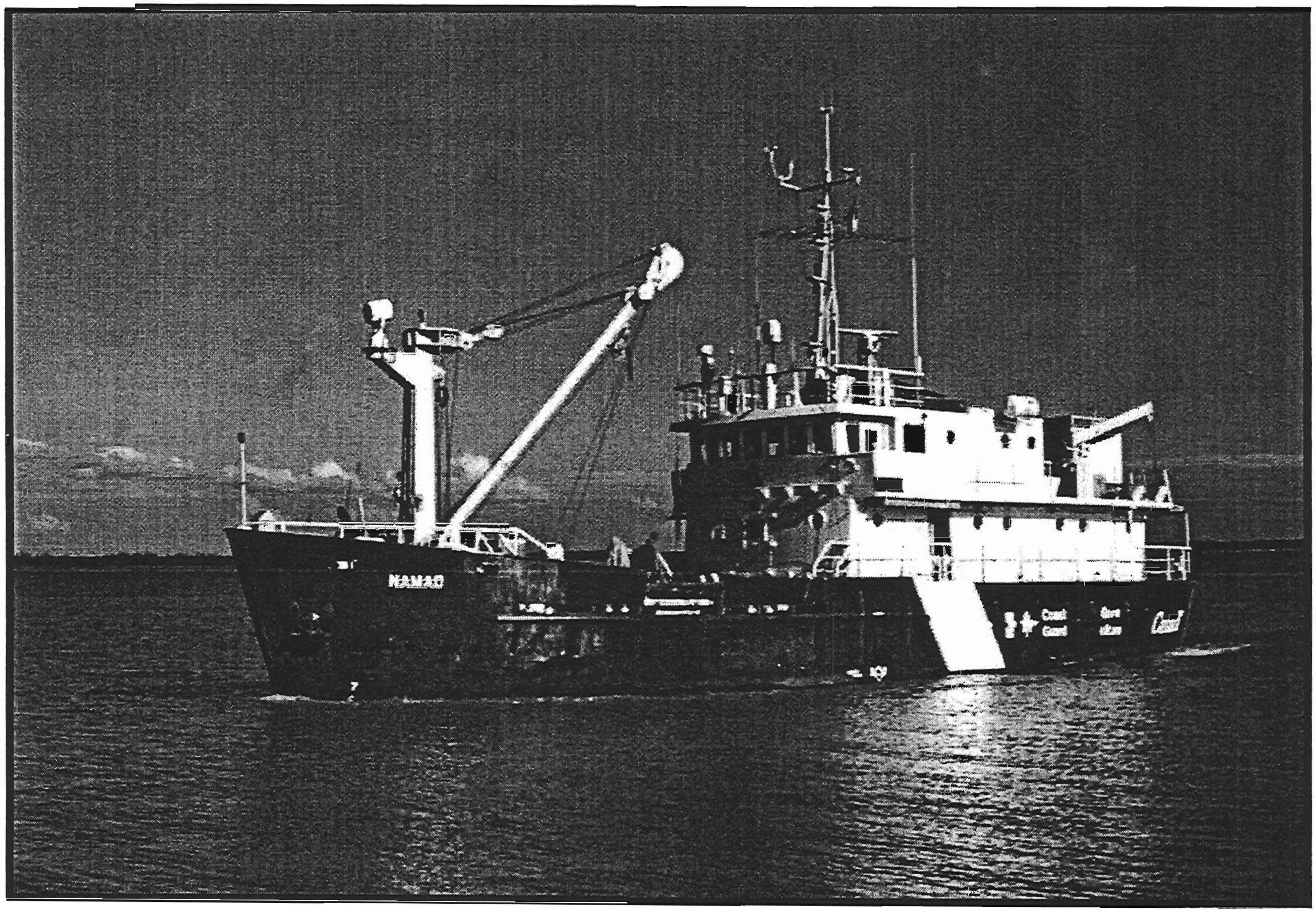


Figure 4. Orientation of ice scour features in the south basin of Lake Winnipeg (from Todd et al., 1998b). The orientation is dominantly NNW-SSE.



GSC photo 1995-174C, L.H. Thorleifson

Figure 5. The CCGS *Namao*

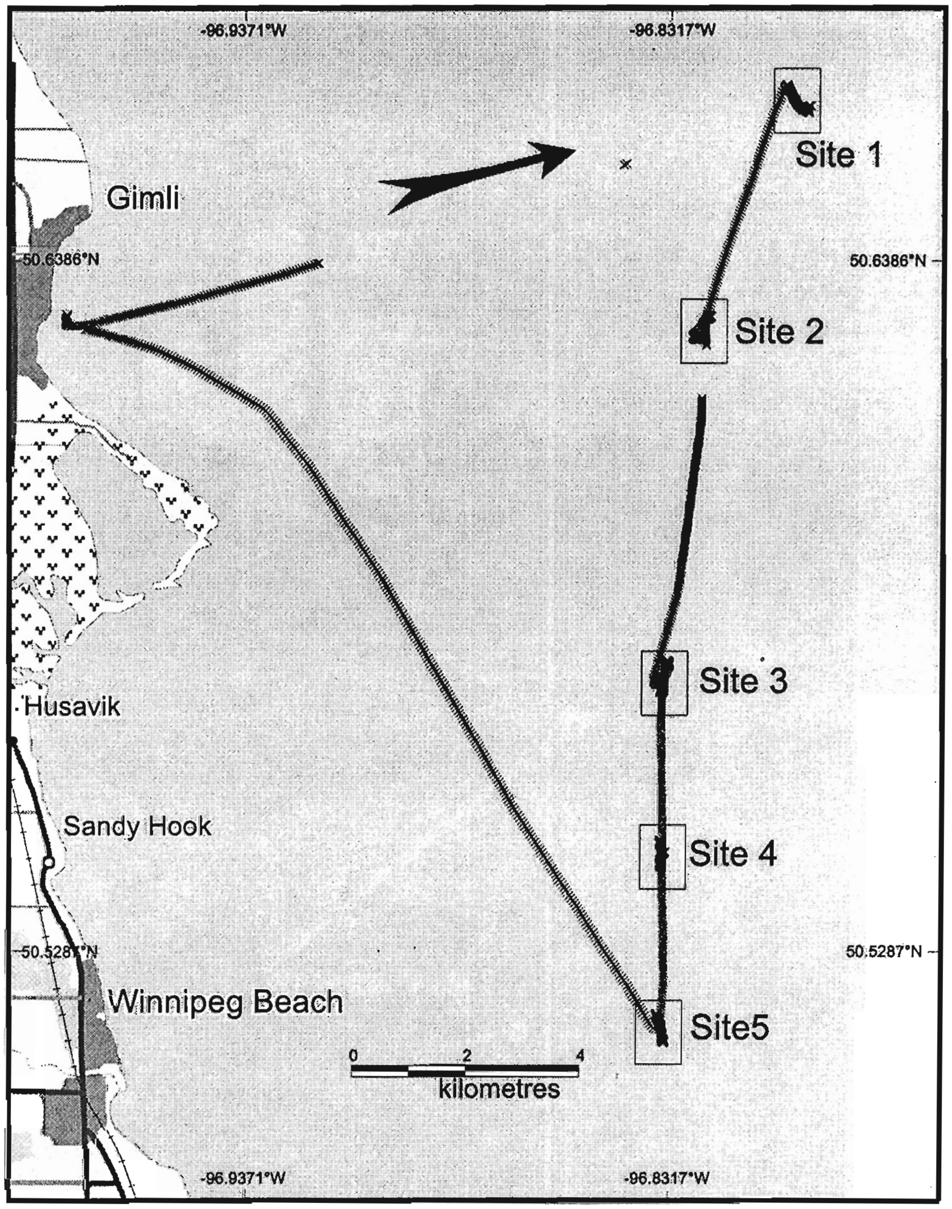


Figure 6. GPS-recorded locations of the *Namao* cruise on August 24, 1999. Departure and return were out of Gimli, Manitoba, and the direction of travel is indicated with an arrow. GPS locations were recorded every 10 seconds. Gaps in the record resulted from instrumental adjustments or maintenance. Boxes indicate the approximate extent of detailed figures.

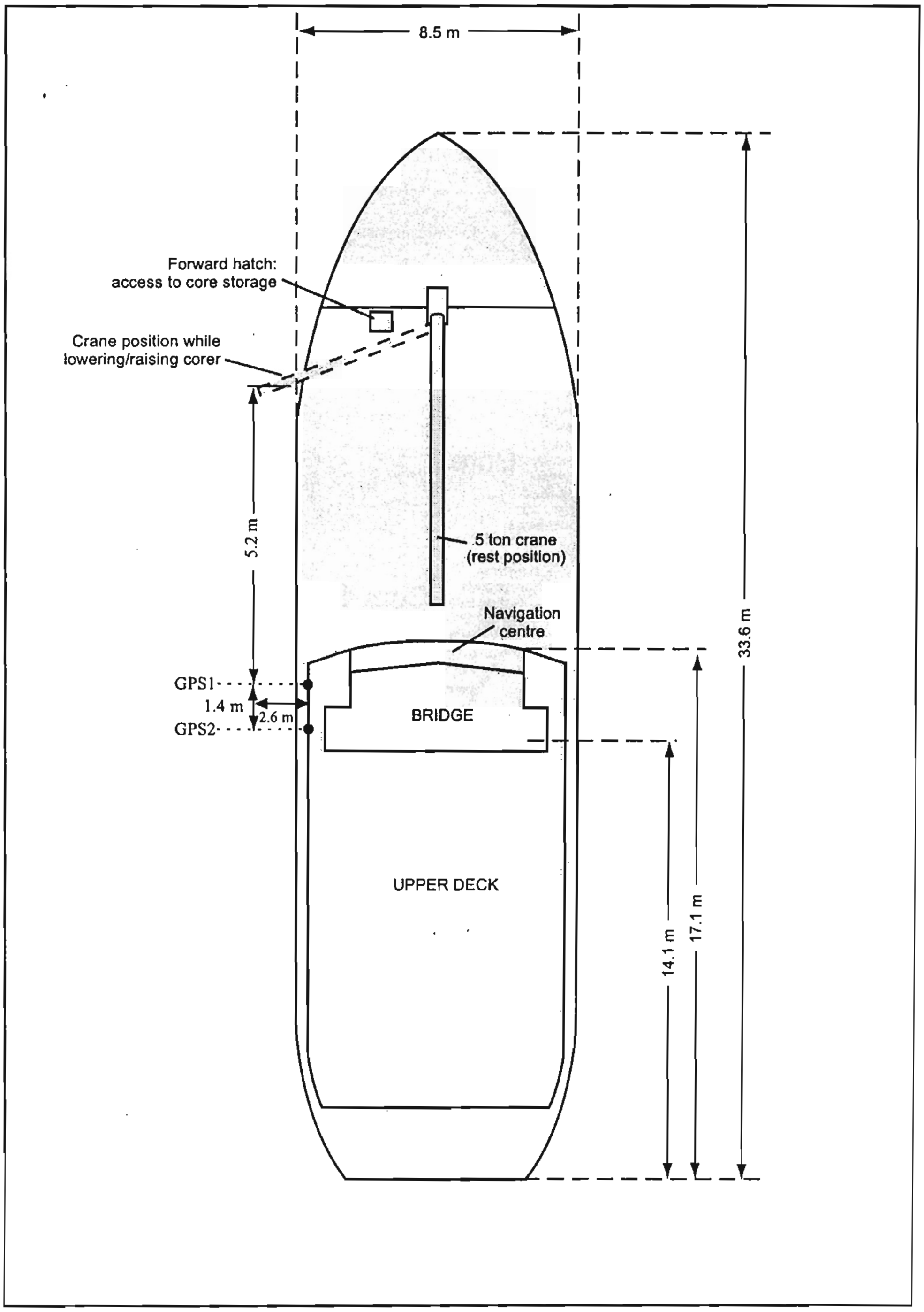


Figure 7. Dimensions and layout of scientific equipment on the CCGS *Namao* for cruise 99-900. Not to scale.

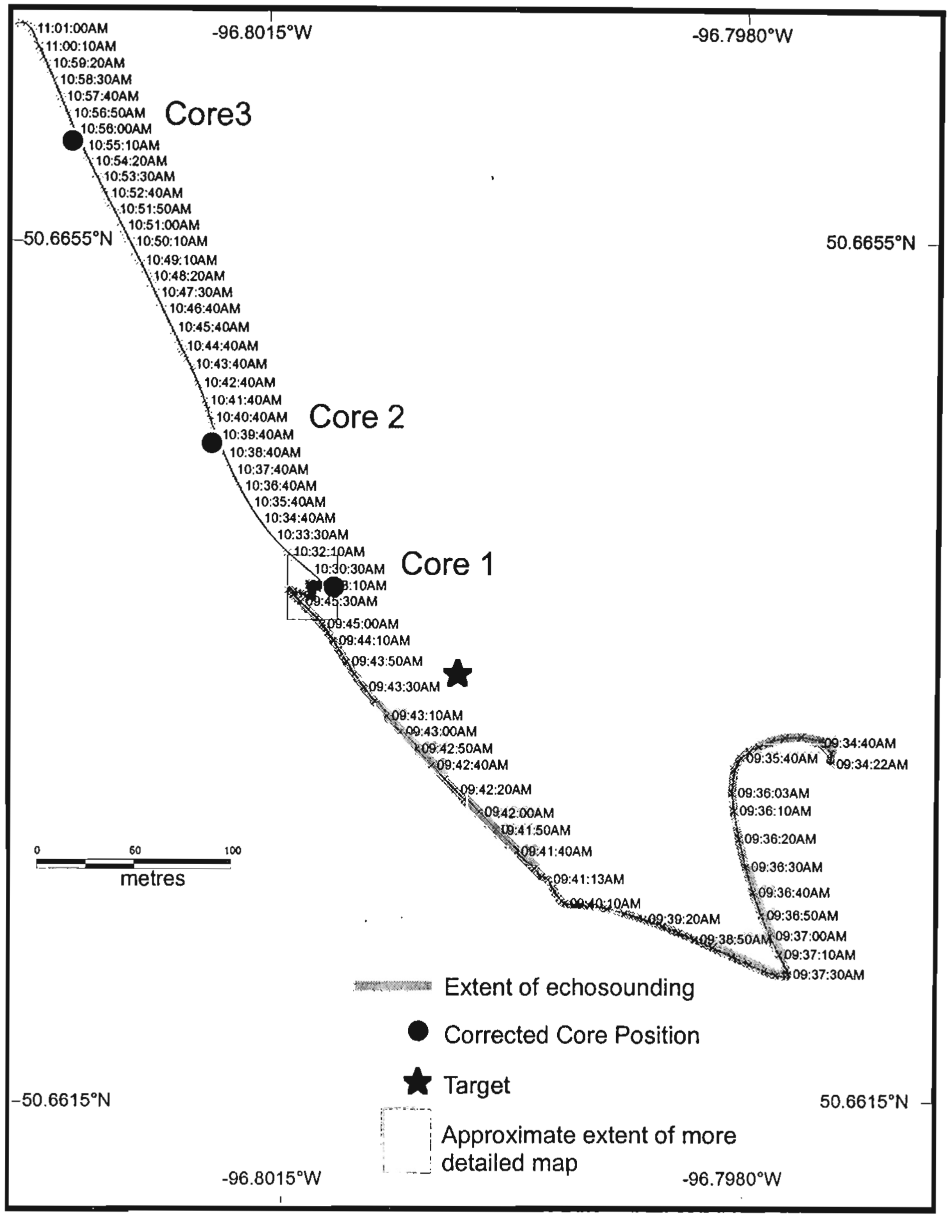


Figure 8. GPS-recorded locations of the ship's track at site 1. Times are local.

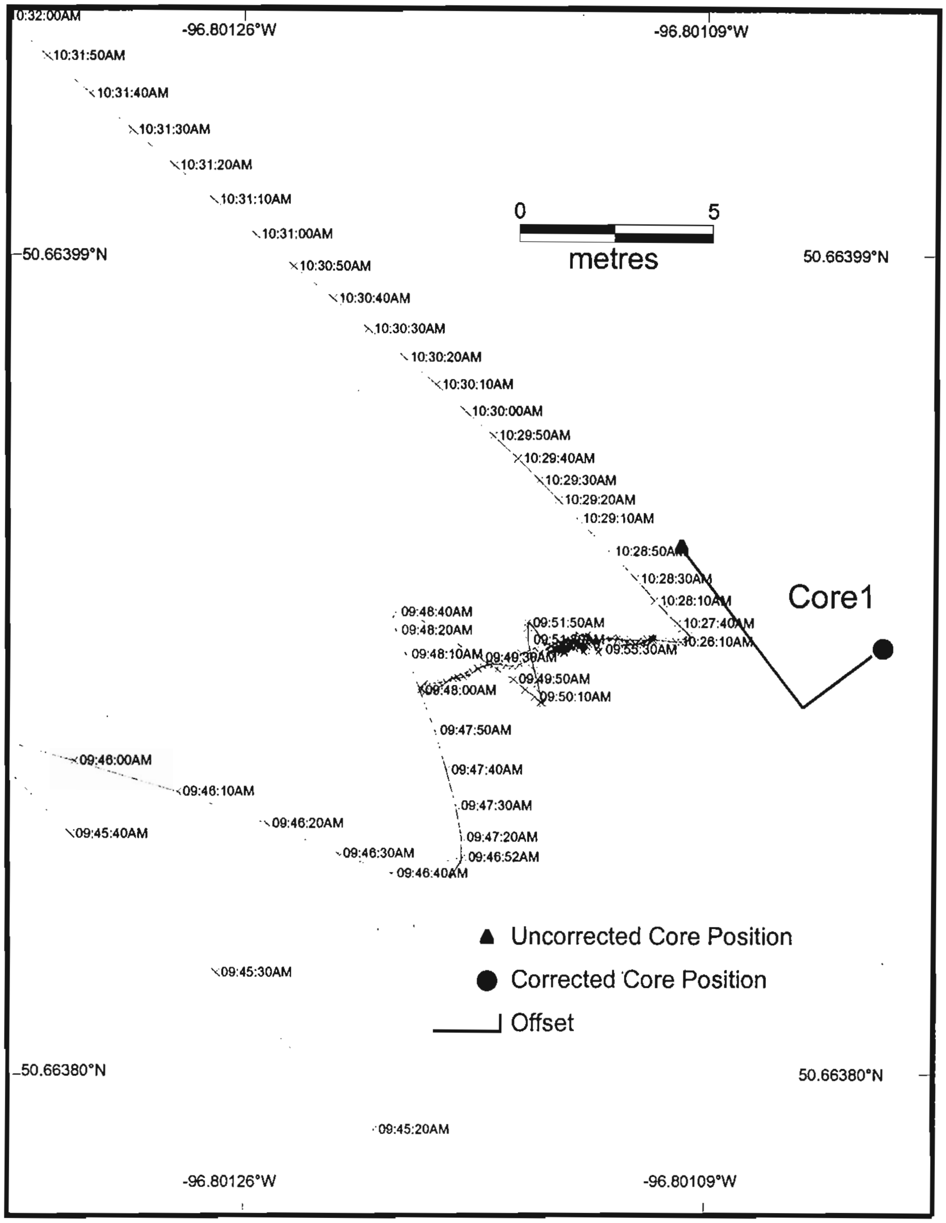


Figure 9. Detail of GPS-recorded locations at site 1, indicating position of core 1. The offset of the coring location from the GPS antenna is shown. Times are local.

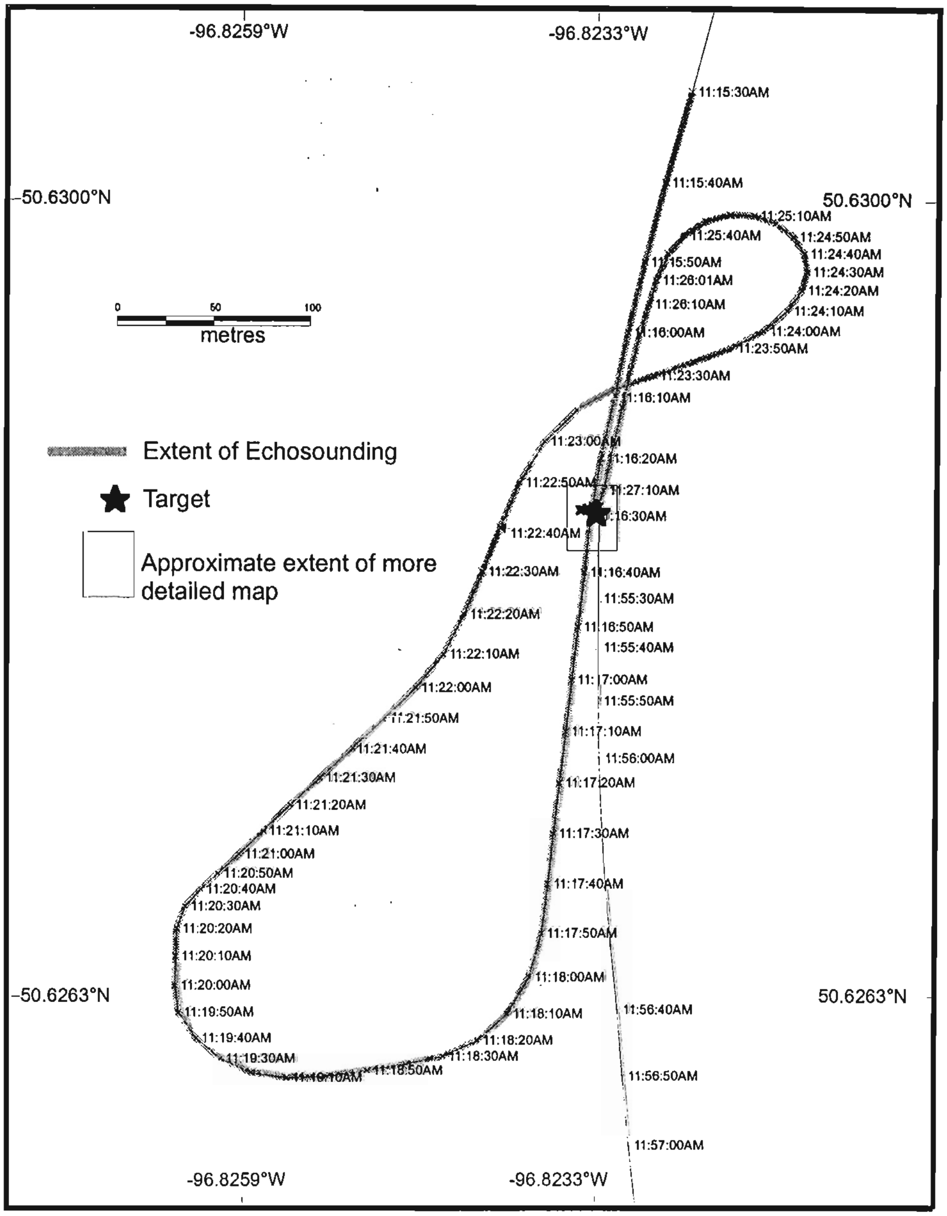


Figure 10. GPS-recorded locations of the ship's track at site 2. Times are local.

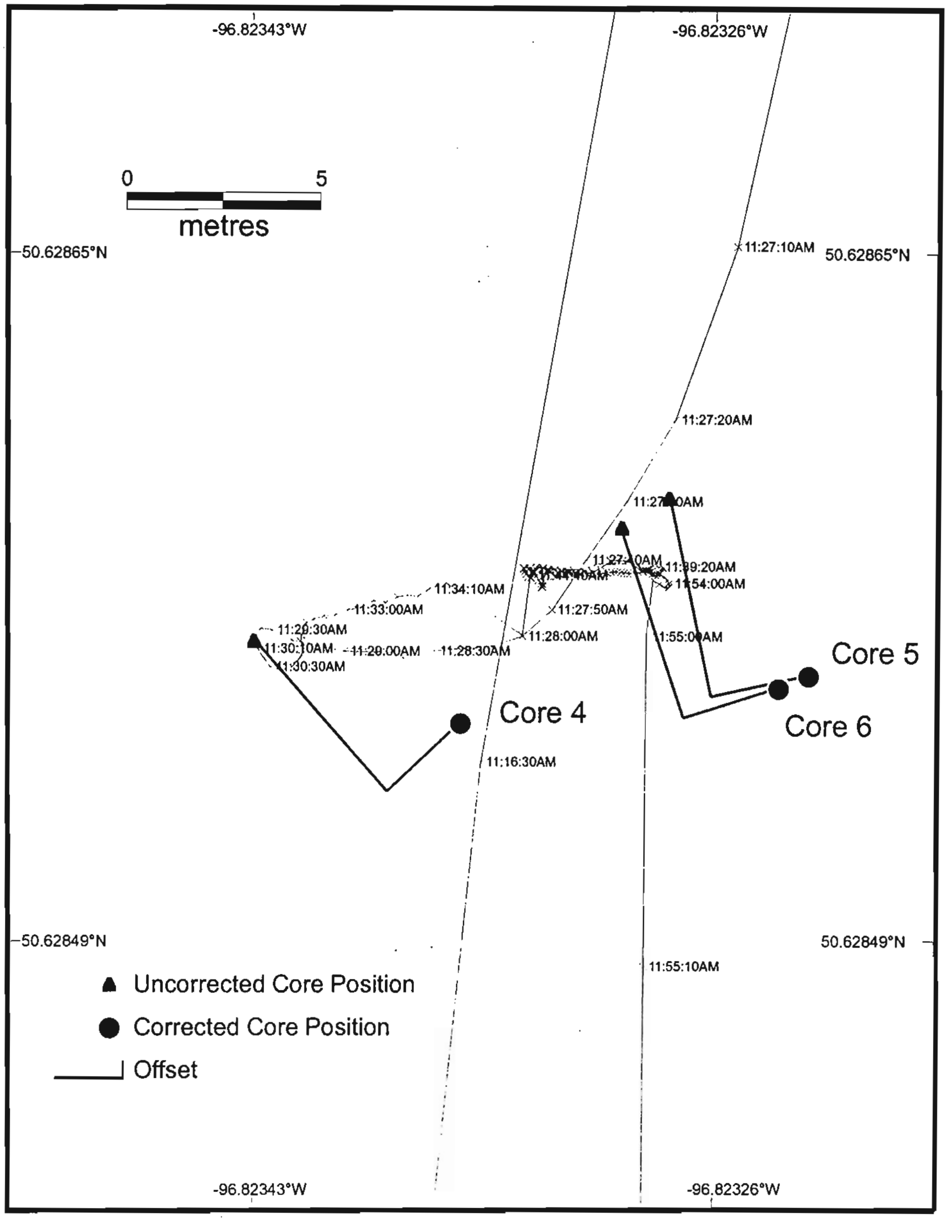


Figure 11. Detail of GPS-recorded locations at site 2, indicating position of cores 4, 5 and 6. The offset of the coring location from the GPS antenna is shown. Times are local.

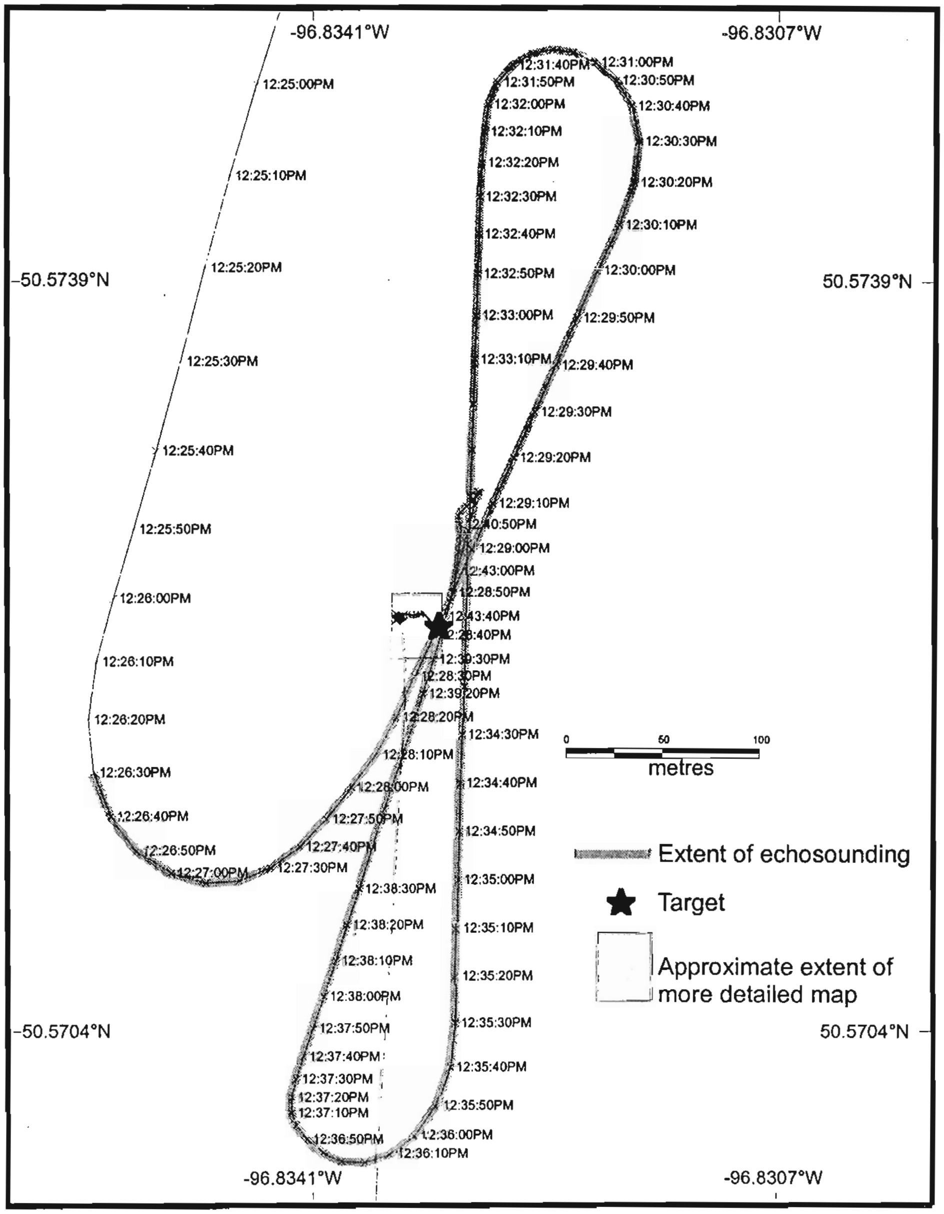


Figure 12. GPS-recorded locations of the ship's track at site 3. Times are local.

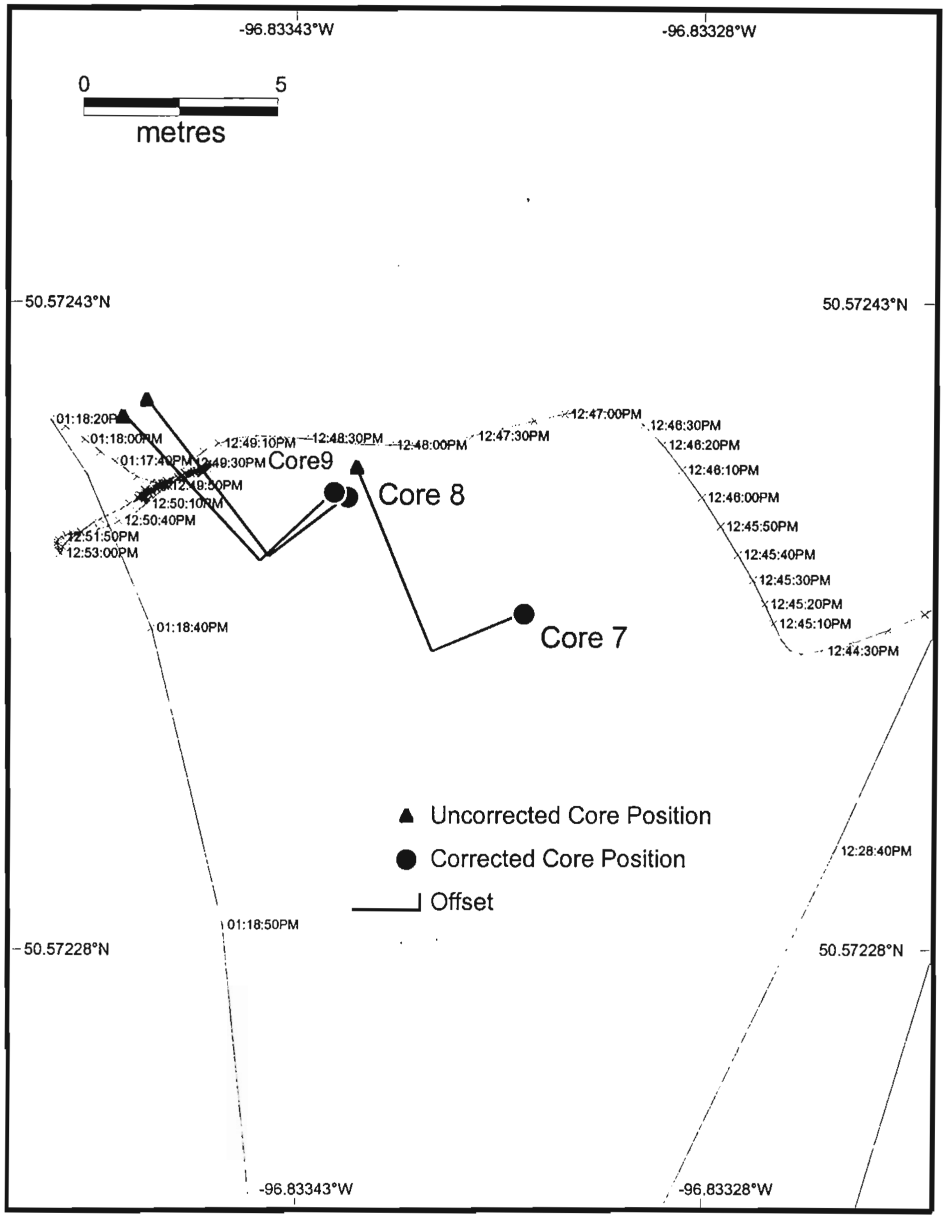


Figure 13. Detail of GPS-recorded locations at site 3, indicating position of cores 7, 8 and 9. The offset of the coring location from the GPS antenna is shown. Times are local.

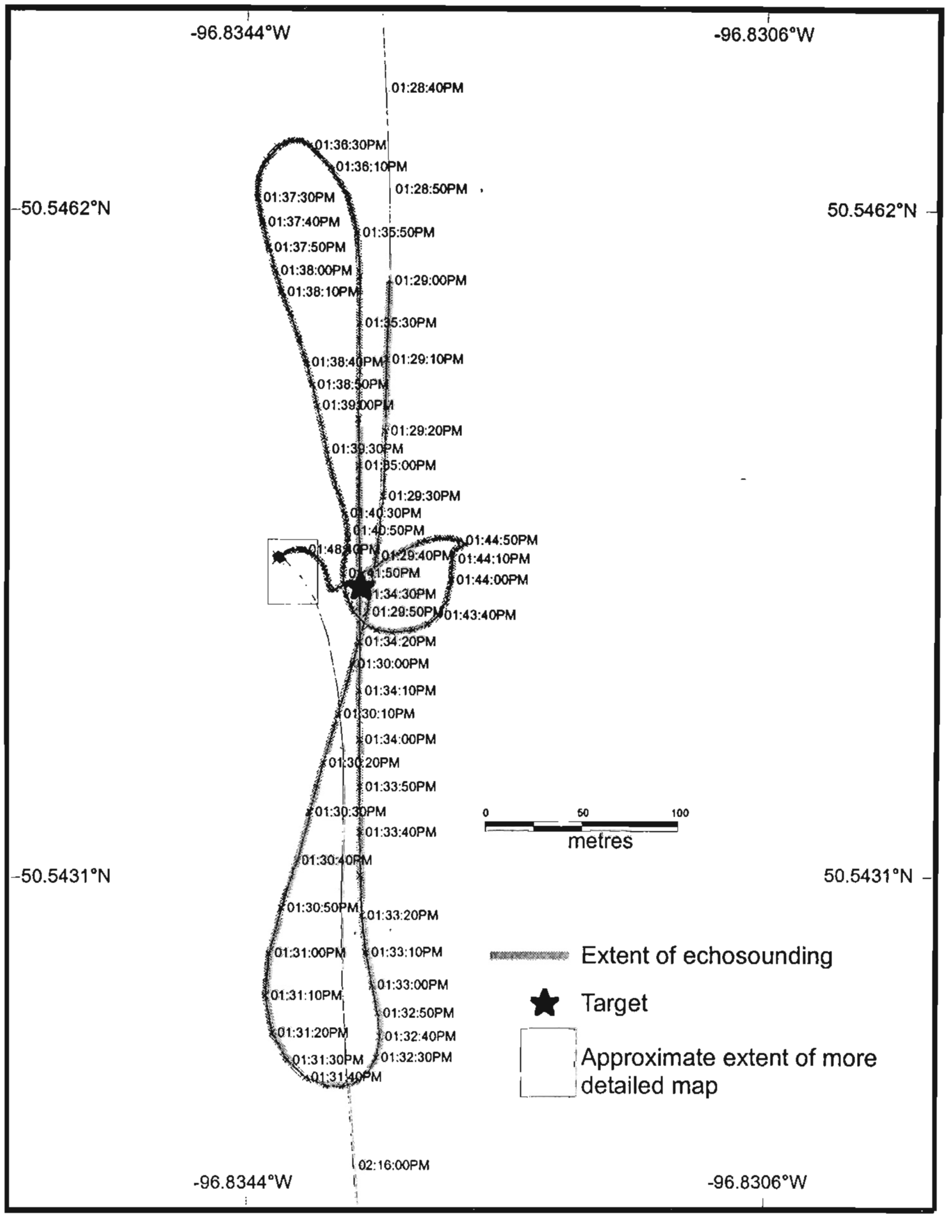


Figure 14. GPS-recorded locations of the ship's track at site 4. Times are local.

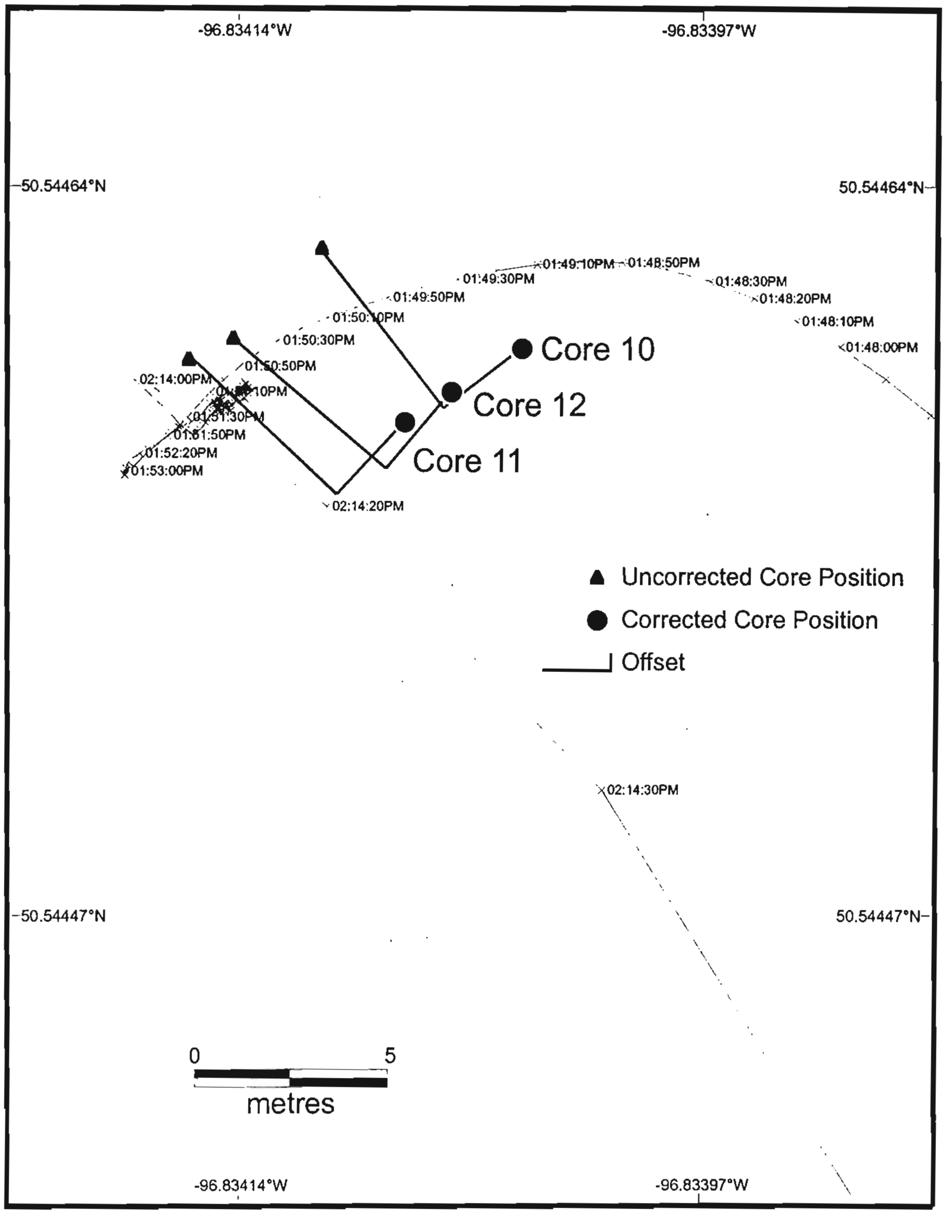


Figure 15. Detail of GPS-recorded locations at site 4, indicating position of cores 10, 11 and 12. The offset of the coring location from the GPS antenna is shown. Times are local.

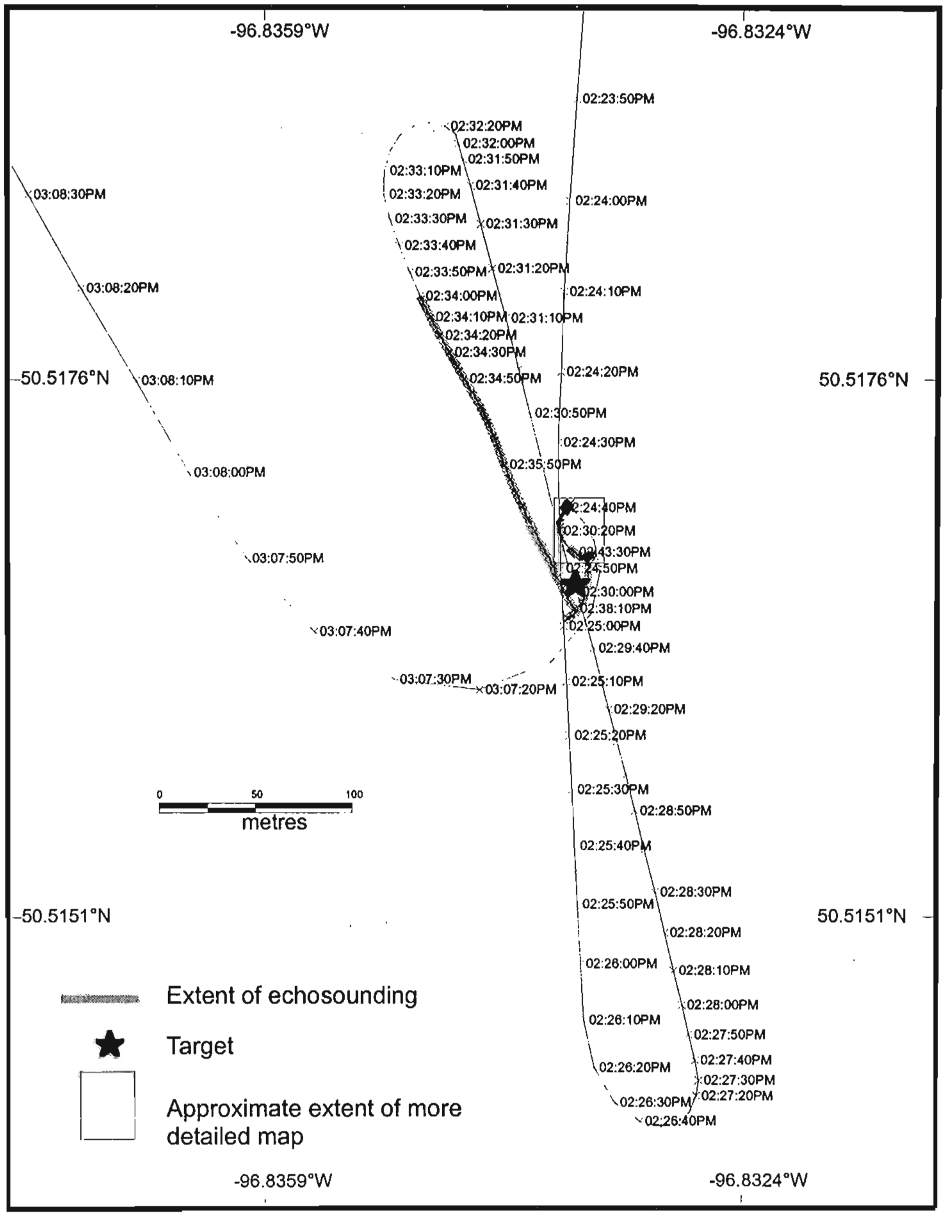


Figure 16. GPS-recorded locations of the ship's track at site 5. Times are local.

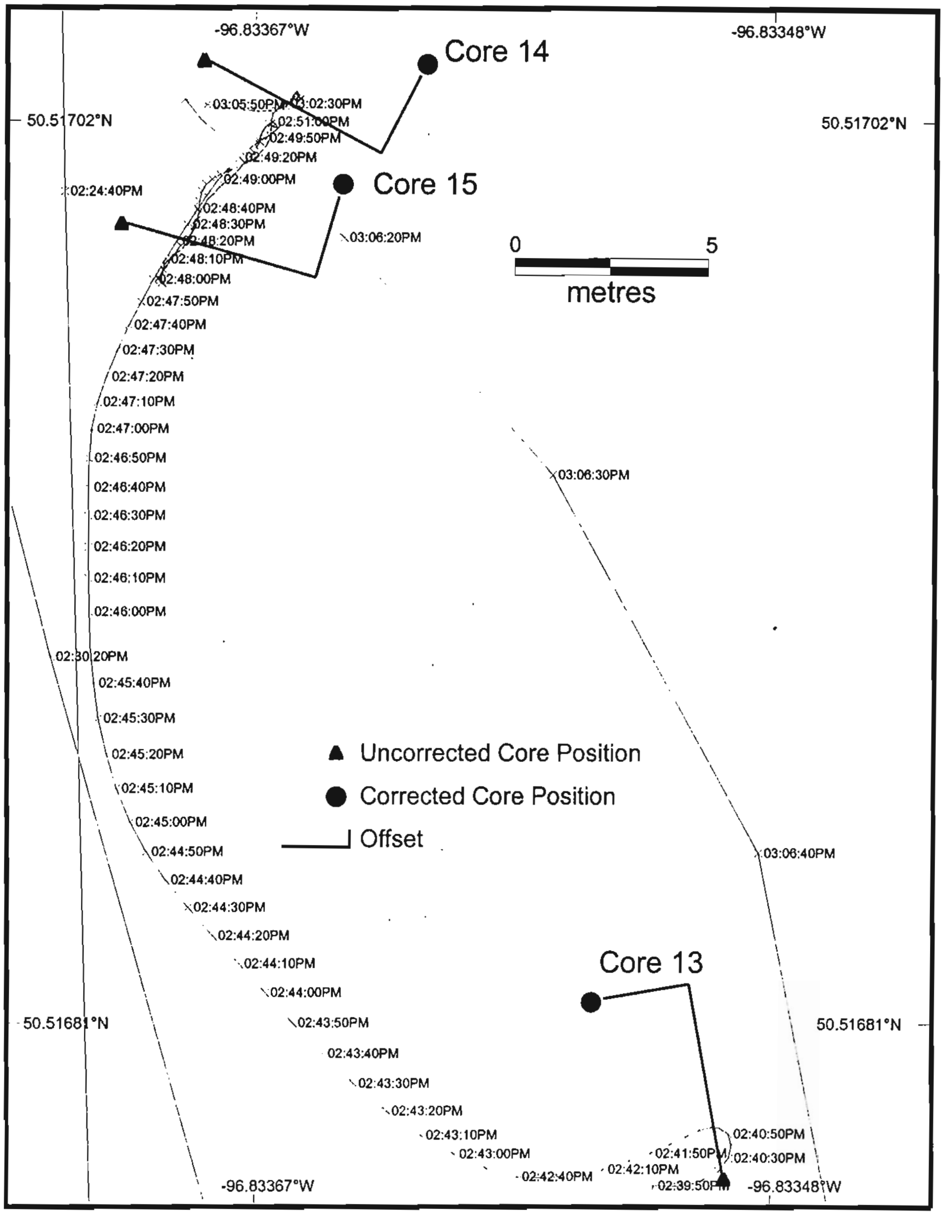


Figure 17. Detail of GPS-recorded locations at site 5, indicating position of cores 13, 14 and 15. The offset of the coring location from the GPS antenna is shown. Times are local.

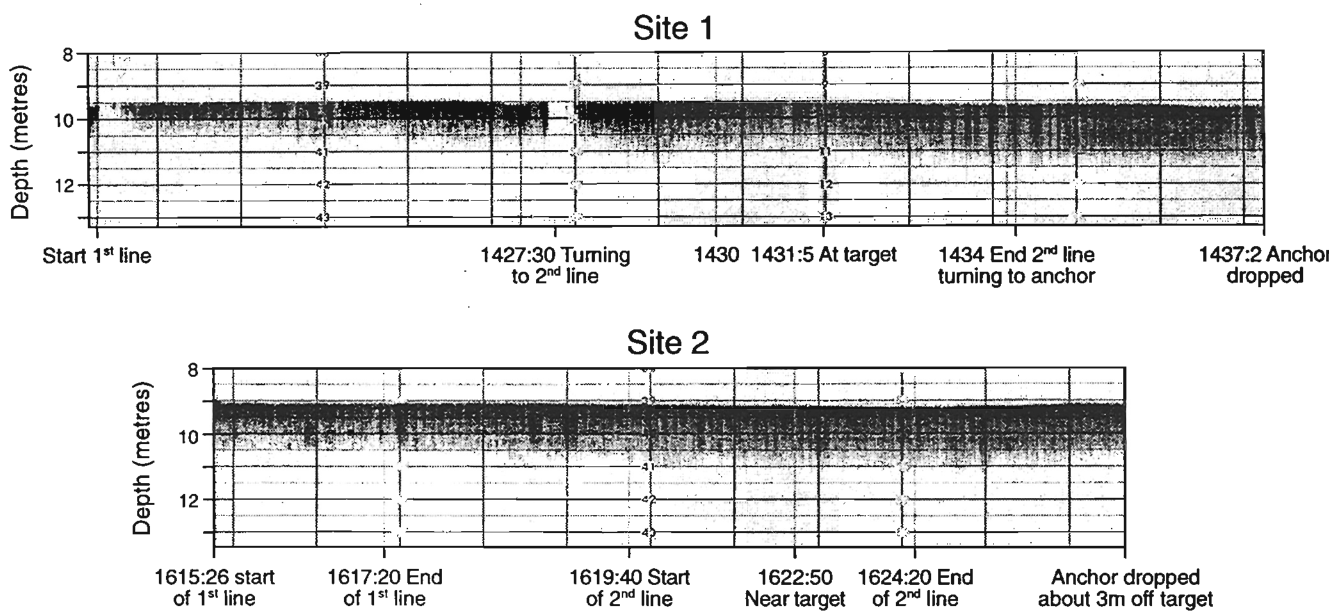


Figure 18. Echo sounding profiles at Lake Winnipeg coring sites.

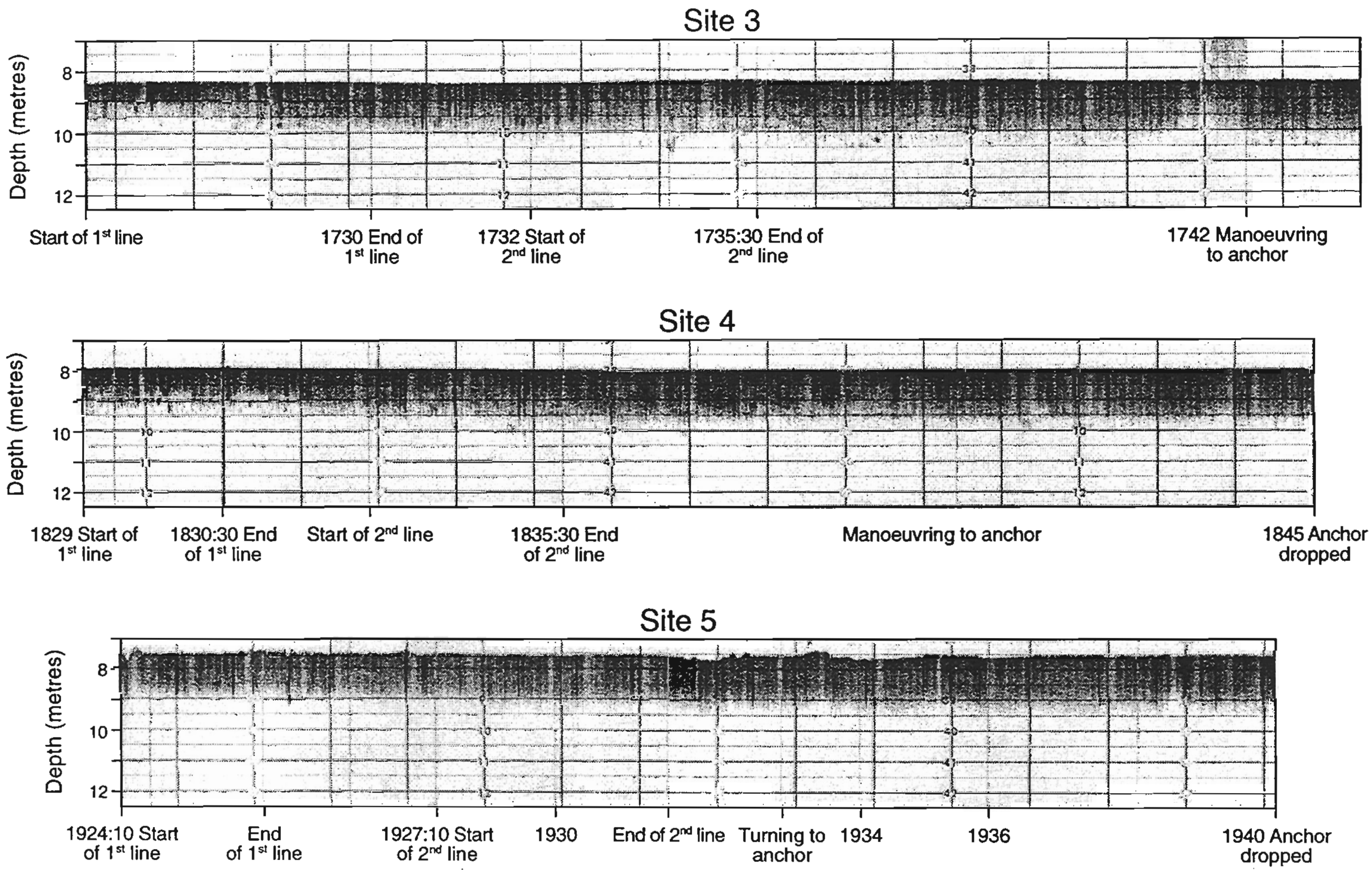


Figure 18 continued

GSC photo 2002-424, L.H. Thorleifson

Figure 19. Example of a gravity corer

4. Geochronological analyses of the cores

4.1 Physical properties and paleomagnetic dating of Lake Winnipeg 99-900 cores

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ABSTRACT

Following the 1997 Red River flood, research addressing the history and controls on the flood hazard included analysis of sediments in Lake Winnipeg to assess flood history and drainage basin evolution. To do so, 15 cores, each about 1.5 m long, were collected from the south basin during a cruise of the Canadian Coast Guard Ship (CCGS) Namao in August 1999, designated Geological Survey of Canada (GSC) cruise 99-900. Ten weeks following collection, whole core physical property (GEOTEK® logging) and paleomagnetic analyses for all 15 cores were completed at the University of Rhode Island, to assess the character of the sediments, test for the presence of trends and/or events in offshore sedimentation, and to obtain preliminary age models prior to selection and splitting of cores. Recurrent physical property trends and coherent paleomagnetic inclination trends indicated that most of the cores are of high quality, not disturbed, and that data from selected cores are likely to be representative of the offshore sediments. Paleo secular variation (PSV) records of the cores were correlated to a radiocarbon-dated regional PSV curve. Paleomagnetic inclination marker I0 was inconsistently identified in the cores. Paleomagnetic inclination marker I1, previously dated between 870 and 1190 yrs BP in lakes in Oregon and Minnesota, was identified in the lower portion of the majority of the cores, thus indicating that the cores represent about 1000 years of sedimentation. The I1 marker was subsequently dated at 810 ± 35 yrs BP (CAMS-84850), calibrated to AD 1230 +50/-70, using an AMS radiocarbon date of an insect sample at the depth of the I1 marker in one of the cores. Correlation of the I1 marker indicated more rapid sedimentation at the more northerly sites. Six cores, at least one from each site, were split and as massive to diffusely laminated soft, dark olive grey, noncalcareous silt and clay with black streaks and mottling related to iron sulphide. Based on these observations, but with preference for sites closest to the Red River mouth, cores 3, 4, and 8 from the three most northerly sites were selected for detailed sampling at 1-cm spacing.

INTRODUCTION

The Red River flood of 1997 was a major disaster that drove 103,000 people from their homes. Much is being done, however, to reduce comparable damage and disruption in the future through enhanced dikes and diversions, as well as revised land use and water management practices. The design of these works requires an optimal understanding of the risk. Research therefore has addressed the nature of the largest known flood, in 1826, whether comparable large floods have occurred in recent centuries, and how geomorphic, climatic, land use, and tectonic factors may be changing the flood hazard. These issues are being addressed by examining the geomorphic processes governing evolution of the Red River, archival records of flood history, floodplain stratigraphic records, tree-ring records, changes in valley gradients, and by examining the stratigraphy of Lake Winnipeg sediments (Thorleifson et al., 1998). The coring in Lake Winnipeg, receiving basin of waters from the Red River, was designed to sample sites most likely to have recorded any influx of sediments from the Red River that may have occurred. In addition to recording gradual changes in Red River sediment transport, it was thought that flood events might be recognizable, due to unique properties allowing differentiation from other sediments in the lake, although it was unclear what attribute would best distinguish flood-related sediments. The cores therefore were thoroughly analyzed for chronology, as well as for a broad range of physical, chemical and biological properties to determine which, if any, would record a history of flooding.

The first step in this suite of analyses was an assessment of the lithology and age of the sediments at the University of Rhode Island. Paleomagnetic inclination markers I0 and I1, identified in most of the cores, provided ages for the upper and lower portions of the cores. A chronological model for the cores was developed using age determinations obtained by radiocarbon, Pb-210, Cs-137, palynological and paleomagnetic analyses (Wilkinson and Simpson, this volume).

LAKE WINNIPEG

Lake Winnipeg, located in central North America, is the eleventh largest lake in the world, having an area of 24,000 km² (Hutchinson, 1975). The lake straddles the contact between Paleozoic carbonate rocks to the west and Precambrian igneous and metamorphic rocks of the Canadian Shield to the east. A smaller south basin, approximately 90 km by 40 km, is separated from a north basin, approximately 240 km by 100 km, by a narrow passage known as The Narrows. The glacially-scoured depression in the rocks underlying the lake, with a depth of

* Italicized text is repeated in each chapter

50-100 m, is largely filled with fine-grained glacial Lake Agassiz sediments, overlain by up to 15 m of post-glacial Lake Winnipeg sediments (Todd and Lewis, 1996). The bathymetry of the lake is shallow and the bottom is flat, with depths averaging 9 m in the south basin and 16 m in the north basin. The lake has a catchment area extending from the Rocky Mountains to very near Lake Superior, including the basins of the Winnipeg, Saskatchewan, Red, Dauphin and numerous smaller rivers. Outflow from the lake is north to Hudson Bay, through the Nelson River. Post-glacial uplift has caused the north end of the basin to rise relative to the south, causing a gradual rise of lake levels that continues at present (Lewis et al., 2000, a). The mean annual temperature of the region, recorded at Gimli, is +1.4°C, although the continental climate of the region ranges from hot summers to very cold winters. The mean annual precipitation is 50.8 cm. The lake is ice free from early May to late November (Ice Thickness Climatology, 1992) and ice cover from November to May is consistently thick and continuous. The lake waters are poorly stratified to unstratified and during the summer months water temperatures range from +17°C in the north basin to +19.5°C in the south basin (Todd, 1996), hence bottom sediment temperatures are equally warm in mid-summer. The lake supports a commercial fishery, it is a major destination for recreation, and lake levels are regulated to optimize hydroelectric power generation on the Nelson River.

SAMPLING AND ANALYTICAL METHODS

Selection of five sampling sites in the south basin of Lake Winnipeg was based on proximity to the Red River mouth and on the absence of ice scour on sidescan sonar records previously obtained in 1994 on the 94-900 Namao cruise (Lewis et al., this volume) (Figure 1). Site 5 was the southernmost point on the north-south survey line that lacked ice scour. Sampling was conducted in calm weather on August 24, 1999 from the CCGS Namao. Three cores were obtained at each of the five sites using a gravity corer consisting of a 100 kg weightstand over a 2 m steel pipe with a 10 cm diameter plastic liner tube. The length of the cores ranged from 107 cm to 170 cm. The cores were sealed, labelled and transported to Gimli, Manitoba on August 29, where they were refrigerated, and subsequently transported via refrigerated truck to the GSC Atlantic core storage facility in Dartmouth, N.S. A monitoring device attached to the core bundle indicated that the sediments did not exceed a temperature of 19°C at any time during transport.

The cores were then transported to the University of Rhode Island, where the first phase of processing and analysis for physical and paleomagnetic properties was completed in October 1999 (Table 1). In order to characterize the sediments, all 15 cores were analyzed for physical properties, useful for assessing variations in the lithology of the sediments as well as the degree of correlation amongst cores and the degree of disturbance of the sediments. Physical properties, including gamma density, P-wave velocity and magnetic susceptibility, and paleomagnetic properties, including declination, inclination and intensity, were measured on whole cores. Cores 4, 5, 6, 7, 8, 9, 10, 13, 14 and 15 were cut perpendicular to the length of the cores at 121 cm, while core 9 was cut at 112 cm to conform to the maximum length accommodated by the magnetometer. Following examination of these analyses, cores 3, 4, 8, 11, 13 and 14 were deemed to be of higher quality and were split along the length of the cores into an archive and a working half. Digital images of split cores 3, 4, 8, 11, 13 and 14 were then obtained at the University of Rhode Island (URI) and, at a later date, of split cores 3, 4 and 9 at the GSC core storage facility in Dartmouth. RGB colour analysis was obtained from the images of the split cores that were scanned at URI. In 2001, cores 4, 7, 8 and 9 were U-channel sampled and paleomagnetic analyses were run on the U-channels. Comparison of well-documented PSV markers to the radiocarbon-dated equivalent in reference cores facilitated determination of absolute ages at select horizons in the cores. In 2000, the working halves of cores 3, 4 and 8 were sub-sampled at GSC Atlantic at 1-cm spacing for chronological, compositional and paleontological analyses and the archive halves were stored and used only for non-destructive analyses. The entire working halves of cores 5, 7 and 9 were sub-sampled at 5-cm spacing at GSC Atlantic for macrofossil analysis.

Physical properties

Gamma density, P-wave velocity, and magnetic susceptibility were all measured simultaneously using a GEOTEK® Multi-Sensor Core Logging System (MST) in whole-core mode.

Gamma density

Gamma Ray Attenuation Porosity Evaluation (GRAPE) is a measure of the wet bulk density of the sediment, and provides a precise and high-resolution record of lithology and porosity changes. A 10-mCi Cs-137 capsule is used as the gamma-ray source, emitting a 5-mm gamma beam that passes through the core and becomes attenuated by Compton scattering. Compton scattering or attenuation is directly proportional to the number of electrons blocking the gamma beam, hence, measurement of the number of unscattered photons passing through the sediment permits determination of the sediment density. Changes in gamma density were assumed to result only from porosity changes or void space in the core liner.

P-wave velocity

P-wave velocity varies with the lithology, the degree of consolidation and the presence of gaseous sediment and hydrates. This parameter is measured using two roller-bearing transducers. A receiver detects a short P-wave transmitted through the sediment and the travel time is measured and divided by sediment thickness to determine velocity. In order to measure the P-wave velocity, it is essential that there is a good acoustic coupling between the transducers and the core liner or the sediment and the core liner. P-wave velocity is affected by gaps in the core, gaseous sediment, poor conductivity and dewatering of sediment. P-wave velocity results were unsatisfactory due to poor acoustic coupling between the core and the liner and/or the presence of gaps or cracks in the sediments, and are not presented here.

Magnetic susceptibility

Magnetic susceptibility is a measure of the ease with which a substance can be magnetized or the amount of magnetizable material present. It is used mostly as a proxy indicator of changes in composition that can be linked to depositional history. Magnetic susceptibility of the core sections was measured using a Bartington Instruments® loop sensor. A low intensity, non-saturating, alternating magnetic field of known strength is applied to the sample and the strength of the resulting field is measured. If the sensor is placed near anything that is susceptible to magnetization, the oscillator frequency will change accordingly. This change in frequency is then converted to magnetic susceptibility, which is reported as a ratio of the strength of the induced field to that of the applied field. The sensor is particularly sensitive to temperature fluctuations, so the core sections were allowed to equilibrate to room temperature before logging. High concentrations of ferromagnetic materials, especially magnetite, and magnetic iron sulphides, including pyrrhotite, result in determination of magnetic susceptibility with high values. Other iron-bearing minerals, including goethite and hematite, also commonly exhibit positive magnetic susceptibility values, although of a smaller magnitude. Conversely, pyrite, quartz and calcite are characterized by slightly negative magnetic susceptibility.

Paleomagnetic analyses

NRM whole-core analyses

The whole cores were passed through a 2-G Enterprises® cryogenic magnetometer system with a 12.5 cm access for measurement of paleomagnetic parameters. The natural remnant magnetization (NRM) was measured at 2-cm intervals, and then each section was subjected to alternating field demagnetization at 10.0 mT and 15.0 mT and re-measured. The resulting data are reported as declination, inclination and intensity.

Declination is the angle of deviation between geographic north and magnetic north in the horizontal plane, inclination is the dip angle of the magnetic vector below the horizontal plane and intensity is the magnitude of the field. Geomagnetic secular variation (SV) is the typical temporal variation of the three components of the Earths' magnetic field between polarity transitions.

NRM U-channel analyses

U-channel samples, consisting of 3 cm by 3 cm square longitudinal subsamples, were obtained from selected cores to obtain higher resolution mineral magnetic and paleomagnetic data. The U-channels were subjected to several higher demagnetization steps for NRM, anhysteretic remanent magnetization (ARM) and isothermal remanent magnetization (IRM).

Digital imaging and RGB colour analyses

Digital images of the split core sections of cores 3, 4, 8, 11, 13 and 14 were taken using a 300 dpi digital camera and GEOTEK® acquisition software at URI. These images were deemed unusable for visual description, as they did not capture subtle variations in colour present in the cores, but were, however, judged to be adequate for quantitatively defining colour trends. These split core digital images, acquired using GEOTEK® software, were stored in 20 cm increments and pieced together to create a composite image of the split core section using the GEOTEK® software. The composite image was then used to generate down-core RGB data at 1-cm intervals.

Digital images were obtained for cores 3, 4 and 9 at the GSC core storage facility in Dartmouth. The images, obtained using a digital camera, were of the archive half of cores 3 and 9, and of a U-channel obtained from core 4. Visual examination of the original cores, as well as these images provided the basis for core descriptions.

RESULTS

The GEOTEK® and paleomagnetic results are presented in Figures 2-20. Whole core GEOTEK® data (density and susceptibility) and whole-core paleomagnetic data (declination, inclination, and intensity) are available for all cores. Split-core RGB colour data obtained for cores 3, 4, 8, 11, 13 and 14 is shown in Figures 4, 6, 12, 16, 18 and 19, respectively. U-channel paleomagnetic data obtained for cores 4, 7, 8 and 9 is shown in Figures 5, 9, 11 and 13, respectively.

DISCUSSION

Physical properties

Gamma density

Density values of the sediments in the cores range from about 1.05 to 1.45 g/cc, typical of recently deposited soft muds (Manger, 1966). In core 1, density increases down-core from about 1.2 to 1.3 g/cc, both gradually and through a series of step-wise increases most prominent at about 70 and 120 cm. Also at site 1, core 3 exhibits similar trends and shifts in density values, while core 2 exhibits somewhat less prominent step-wise increases and slightly lower density values (1.15 to 1.25 g/cc). Very similar trends were observed at site 2, although the core break at 121 cm obscures trends at this depth. Density values are slightly higher at this site, ranging from about 1.25 to 1.4 g/cc. At site 3, a step-wise density increase in core 9 at about 110 cm is followed by a step-wise decrease at 120 cm. Again, breaks in cores 7 and 8 at 121 cm make recognition of shifts difficult. The range of density values in core 7 (1.05 to 1.15 g/cc) is lower than those in cores 8 and 9 (1.3 to 1.4 g/cc). Density trends at site 4 and especially site 5 are dominated by sharper, step-wise increases and decreases with values ranging from 1.1 to 1.45 g/cc. The differing character of density trends at these two more southerly sites implies somewhat different conditions. The gradual down-core increase in density observed in all the cores likely is due to compaction (e.g. Hedberg, 1936; Nettleton, 1934). Step-wise increases in density at 70 and 120 cm are likely also the result of compaction, as density-depth relationships typically do not follow a smooth linear relationship (Hedberg, 1936).

Magnetic susceptibility

Magnetic susceptibility values range from about 7×10^{-5} to 17×10^{-5} SI and exhibit down-core increases. For cores 2, 5, 6, 7, 8, 9, 11, 13, 14 and 15, trends in magnetic susceptibility mimic those observed for density, although in some cases this is masked by artificial lows created by cuts in the cores at around 120 cm. Cores 1, 3, 4, 10 and 12 exhibit trends in magnetic susceptibility that differ from those in density. In cores 1 and 4, magnetic susceptibility exhibits a significant step-wise increase around 75 cm, followed by a decrease. Magnetic susceptibility in core 3 exhibits a strikingly different trend than the density record, with a down-core decrease in values. Similarly, cores 10 and 12 show down-core decreases, although not as prominently. The co-variance of density and magnetic susceptibility observed in many of the cores implies that the density of the sediments, interpreted as the degree of compaction, is related to the relative amount of magnetizable material present in the sediments, a property that would increase with increased compaction and dewatering. Intervals where density and magnetic susceptibility differ likely represent depths where the sediments contain differing concentrations of ferromagnetic minerals. One such interval is between 75 and 100 cm in cores 1 and 4. No explanation can be offered for down-core decreases in magnetic susceptibility.

For the three more northerly sites, gamma density and magnetic susceptibility records show similar trends for the cores, with the exception of core 3, which exhibits anomalous magnetic susceptibility results. The observed trends are correlatable amongst the cores, which is supportive of the cores being of high quality and not disturbed.

Paleomagnetic properties

NRM whole-core analyses

Recognizable features in the inclination record previously identified in North American inclination records by Lund (1996) and King et al. (2000) have been labelled as I0 and I1 on the whole core paleomagnetic records. Neither feature was recognized in Core 12 (Figure 11), only feature I1 was recognized in cores 10, 11, 13, 14 and 15 (Figures 15, 16, 18, 19 and 20) and core 1 (Figure 2) did not penetrate to feature I1. King et al. (2000) assigned a radiocarbon age of 225 ± 120 BP to feature I0. The I1 marker has been previously dated at 1190 ± 90 yrs BP in Fish Lake, Oregon (Verosub et al., 1986), 870 ± 120 BP in Elk Lake, Minnesota (Sprowl and Banerjee, 1989), and 960 ± 90 BP in Lake St. Croix, Minnesota (Lund and Banerjee, 1985), thus providing an indication that the cores represent about 1000 years of sedimentation. The I1 marker was subsequently dated at 810 ± 35 yrs BP (CAMS-84850), calibrated to AD 1230 +50/-70, from an insect sample at the depth of the I1 marker in one of the cores (Telka, this volume).

The depth of the I0 and I1 features varies considerably amongst the cores (Table 2), with a range of 69 cm to 151 cm for the lower marker and of 7 cm to 38 cm for the upper marker. While high confidence is placed on the I1 designations, based on consistency and compatibility with other information, the I0 assignments are more problematic, based for example on comparison to radiochemical profiles (Wilkinson and Simpson, this volume). Variation amongst the sites is attributed to a spatially variable sedimentation rate, whereas variations amongst cores at a single site are likely due to coring problems such as inclination of the core barrel during penetration and/or bypassing of sediments. Cores whose quality was suspected to have suffered due to factors such as these were not used for subsequent analyses.

A comparison of the depth of feature I1 in cores obtained along a N-S transect in Lake Winnipeg (Figure 21) reveals a greater sedimentation rate at the more northerly sites, hence, a higher resolution for examining environmental change. Based on these observations and the quality of the paleomagnetic profiles, core 8 (site 3), core 4 (site 2), and core 3 (site 1) were selected as the primary records for detailed study.

NRM U-channel analyses

U-channel directional data from split cores was not of high quality compared to that obtained from the whole cores, and features I0 and I1 cannot be readily identified in the U-channel data, hence, U-channel data were not used to date the cores. The lower quality of this data is likely the result of high water content and the deformation that occurred during splitting and U-channel sampling.

The directional U-channel data obtained from core 9 (Figure 13), however, was of higher quality than that obtained from the other U-channels, so relative paleointensity studies were performed on this U-channel and the results compared to the radiocarbon-dated paleointensity record of Lake LeBoeuf, Pennsylvania (King et al., 1983) (Figure 22). The results of the paleointensity dating were compared with the inclination dating and with an AMS radiocarbon age result obtained from insect remains in core 9 (Telka, this volume). The PSV (paleomagnetic and paleointensity) age estimates obtained from comparisons with regional inclination and paleointensity curves are consistent even though the age scales of the two regional curves are slightly different. The age estimates are fairly consistent and provide the basis for dating the lower sections of the cores.

Digital imaging and RGB colour analyses

Sediments in the split cores consist of soft, dark olive grey, noncalcareous silt and clay with brown to black streaks. In places, the sediments show irregular planar to wavy banding perpendicular to the length of the core, defined by colouration that changes with the length of time the core is exposed to the atmosphere. The irregular bands range from moderately well defined 1-cm thick layers to diffuse multi-cm layers. The banding yields to a mottled appearance in parts of the cores. Abrupt lithological changes were not observed visually.

Sediments from the uppermost 1.5 m of long cores collected on previous cruises in the vicinity of the 1999 cores were described as having Munsell colours ranging from olive grey (5Y 4/2) to grey (5Y 4.5/1) (Lewis et al., 2000, b). For cores collected on the 1999 cruise, RGB colour analysis of split cores at URI showed values ranging from 35 to 70 for red, 30 to 65 for green and 25 to 60 for blue. Conversion of RGB values to Munsell soil colours using Munsell conversion software version 4.01 yielded Munsell colours ranging from 4GY 1/3 to 6Y 2/1, although these values seem dark in comparison to values for previously obtained cores. Uncorrected digital images of the same cores, obtained at the GSC core storage facility, exhibit colour ranges of 60 to 100 for red, 65 to 90 for green and 48 to 80 for blue. Equivalent Munsell colours range from 5GY 2/3 to 4Y 3/2.

All the split cores display down-core increases in RGB colour values from URI, reflecting a down-core shift to slightly lighter-coloured sediments. The increases are fairly gradual, but exhibit step-wise increases at depths of approximately 20, 115 and 140 cm. The subtly darker colour of the more recently deposited sediments may reflect changes in organic composition.

CONCLUSIONS

- Density and magnetic susceptibility trends in several cases can be correlated core to core.
- Physical property and paleomagnetic data indicate that most of the cores are of high quality, and that data from a few selected cores would be representative of the offshore sediments.
- Core-to-core correlation of paleomagnetic marker I1 indicates more rapid accumulation of sediments at the more northerly sites, hence a higher resolution for examining environmental change. Therefore, core 8 (site 3), core 4 (site 2), and core 3 (site 1) were selected as the primary records for subsequent study.
- Paleomagnetic inclination markers I0 and I1 were identified in many of the cores. The I0 marker was assigned a radiocarbon age of 225 ± 120 BP by comparison to reference sites elsewhere, although this marker was not consistent in the Lake Winnipeg cores, and did not compare well with chronology based on Pb-210, Cs-137 or pollen.
- The I1 marker was dated at 810 ± 35 yrs BP (CAMS-84850) from an insect sample at the depth of the I1 marker in one of the cores. This age is consistent with regional age estimates for this marker.
- The sediments observed in the split cores consist of soft, dark olive grey, noncalcareous silt and clay with brown to black streaks presumably related to iron sulphide.

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Table 1. Processing and analysis of Lake Winnipeg 99-900 cores for physical and paleomagnetic properties

	Core No.														
	1	2	[1]3	[1]4	5	6	7	[1]8	9	10	11	12	13	14	15
PROCESSING															
Split			X	X				X	X		X		X	X	
Sliced at 1 cm			X	X				X							
Sliced at 5 cm					X		X		X						
U-channel sampled				X			X	X	X						
ANALYSIS															
Whole-core physical properties:															
GEOTEK® gamma density	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
[2]GEOTEK® P-wave velocity	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
GEOTEK® magnetic susceptibility	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Whole-core paleomagnetic properties:															
Declination	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Inclination	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Intensity	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
U-channel magnetics				X			X	X	X						
[3] Digital images I			X	X				X			X		X	X	
Split-core RGB colour analysis			X	X				X			X		X	X	
[4] Digital images II			X	X					X						

[1]Primary cores

[2]P-wave velocity data were of poor quality and are not presented graphically

[3]Digital images I obtained at the University of Rhode Island

[4]Digital images II obtained at the GSC core storage facility in Dartmouth

Table 2. Depth to paleomagnetic markers I_0 and I_1 in Lake Winnipeg 99-900 cores

Core No.	Depth of I_0 (cm)	Depth of I_1 (cm)
1	38	[1]n.a.
2	18	139
3	~7	126
4	9	132
5	28	120
6	34	115
7	29	151
8	28	120
9	34	114
10	[2]n.a.	73
11	[2]n.a.	80
12	[2]n.a.	[2]n.a.
13	[2]n.a.	101
14	[2]n.a.	69
15	[2]n.a.	81

[1]Core 1 did not penetrate to marker I_1

[2]Marker was not recognized the core

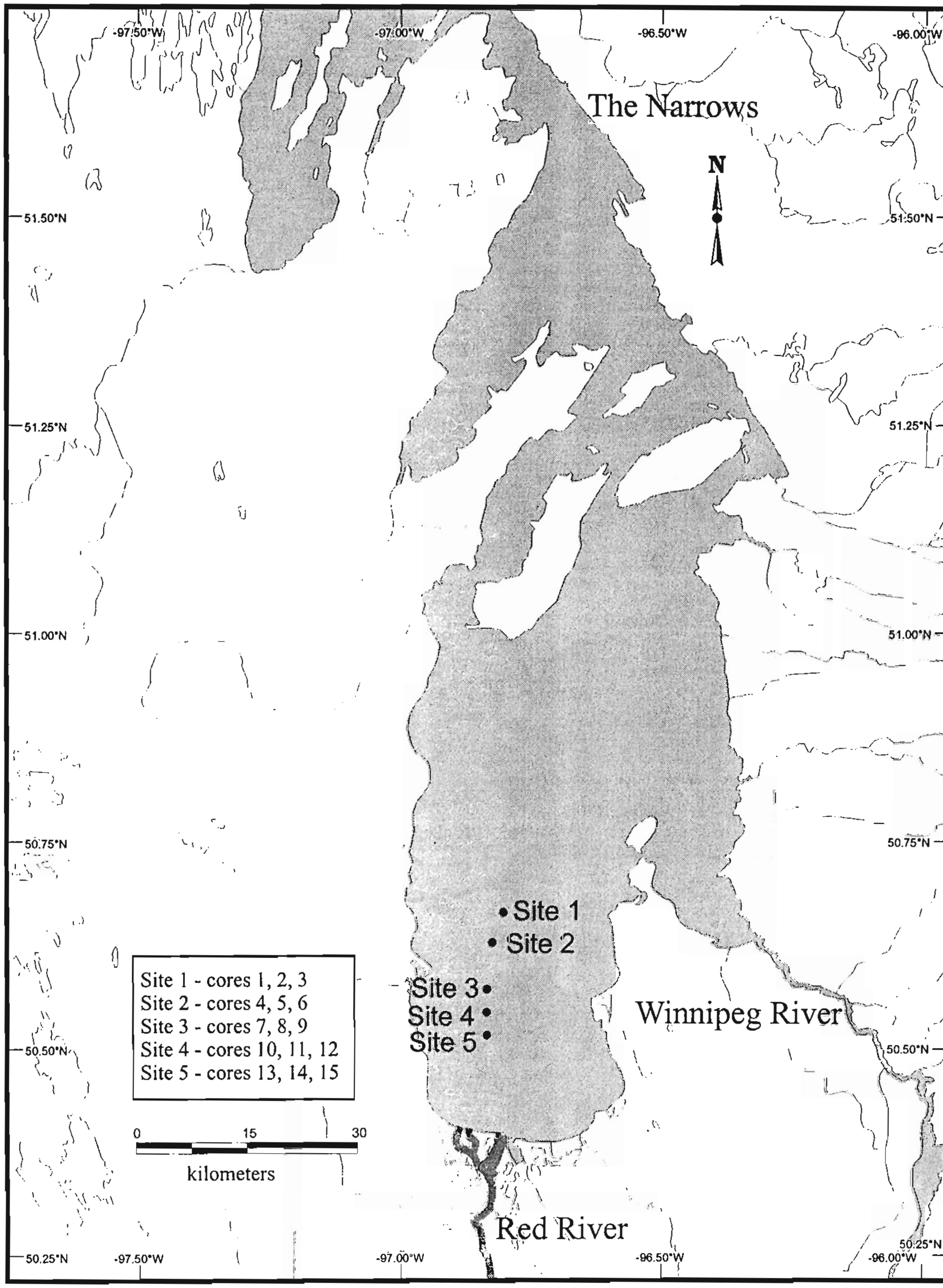

Figure 1. Map of southern Lake Winnipeg showing locations of coring sites

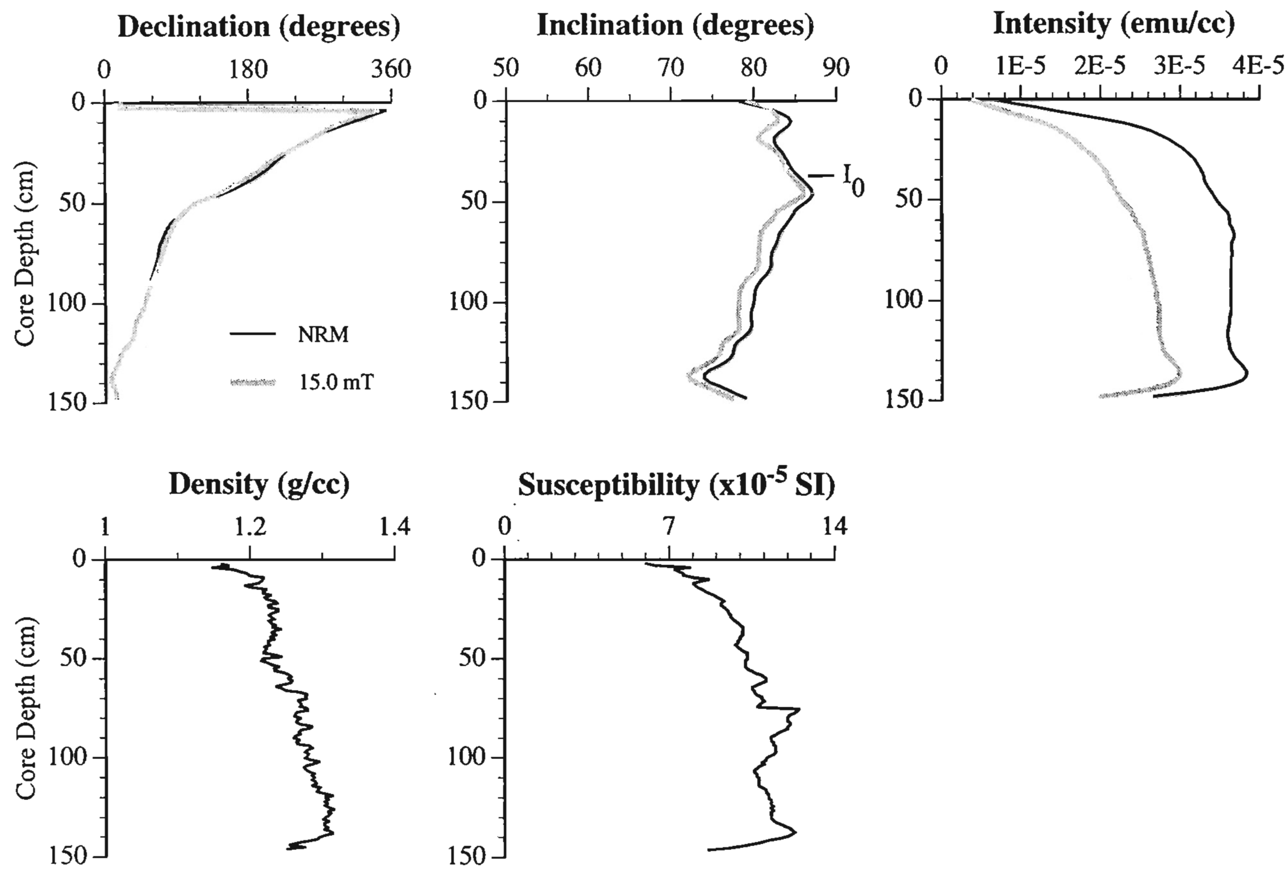

Figure 2. Down-core measurements of paleomagnetic and physical properties for Lake Winnipeg 99-900 Core 1.

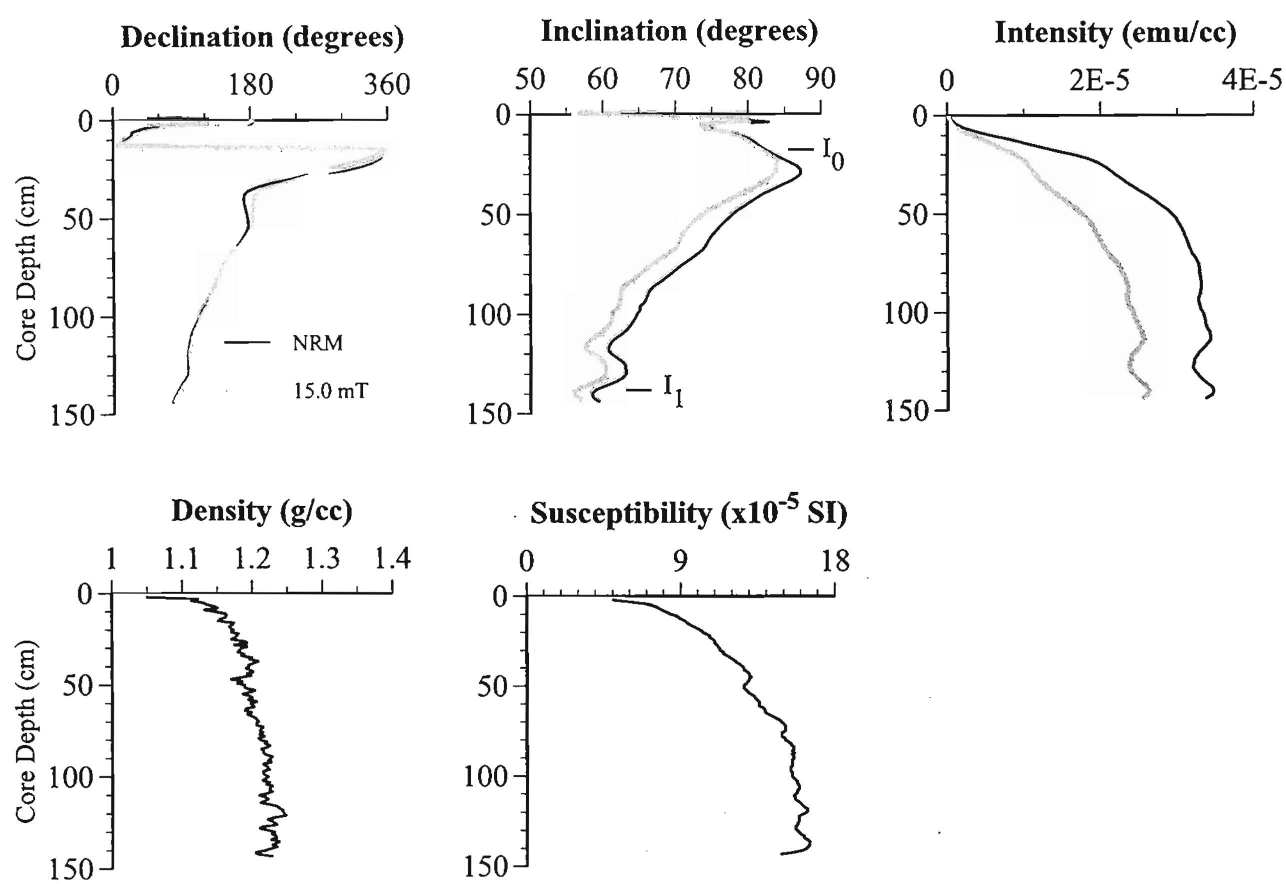

Figure 3. Down-core measurements of paleomagnetic and physical properties for Lake Winnipeg 99-900 Core 2.

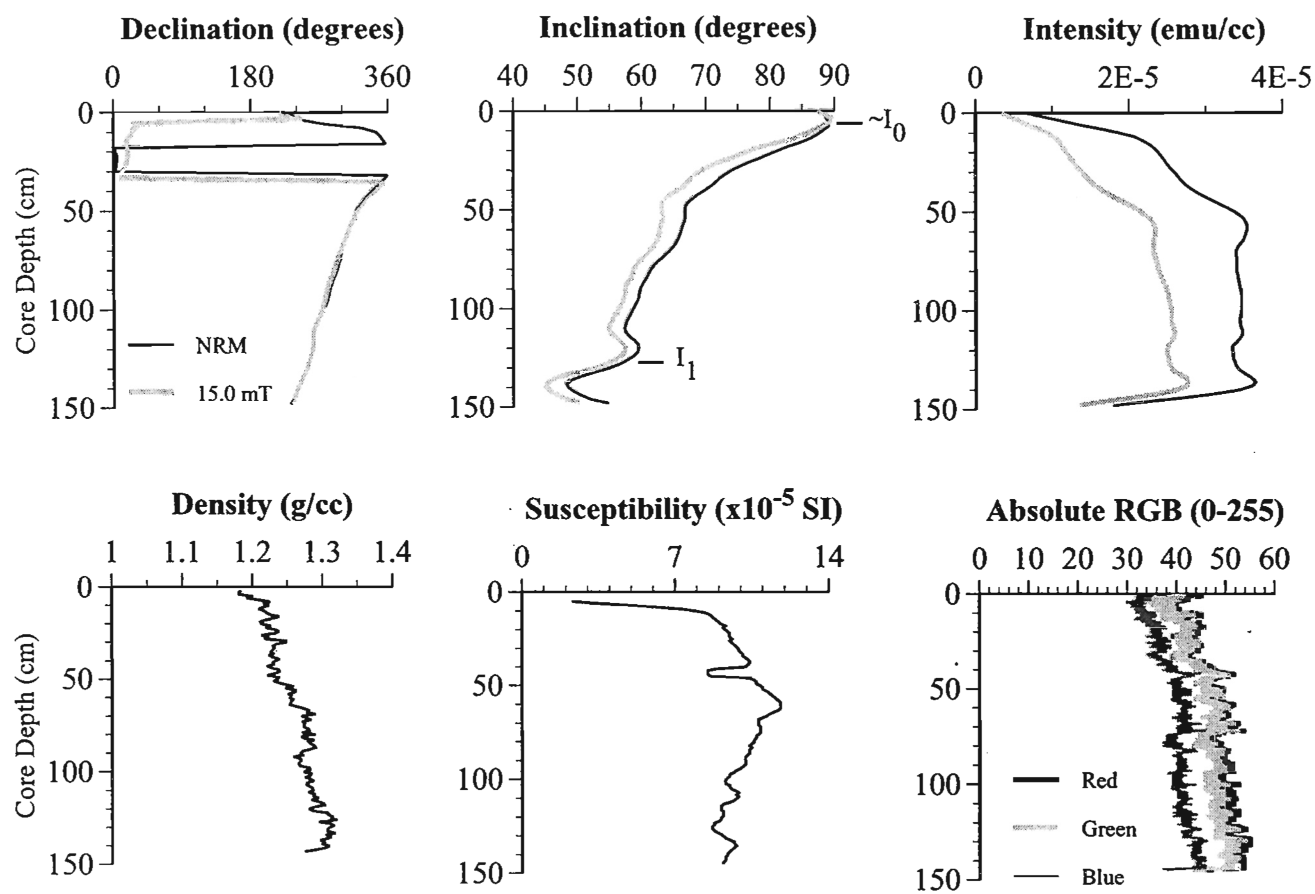

Figure 4. Down-core measurements of paleomagnetic and physical properties for Lake Winnipeg 99-900 Core 3.

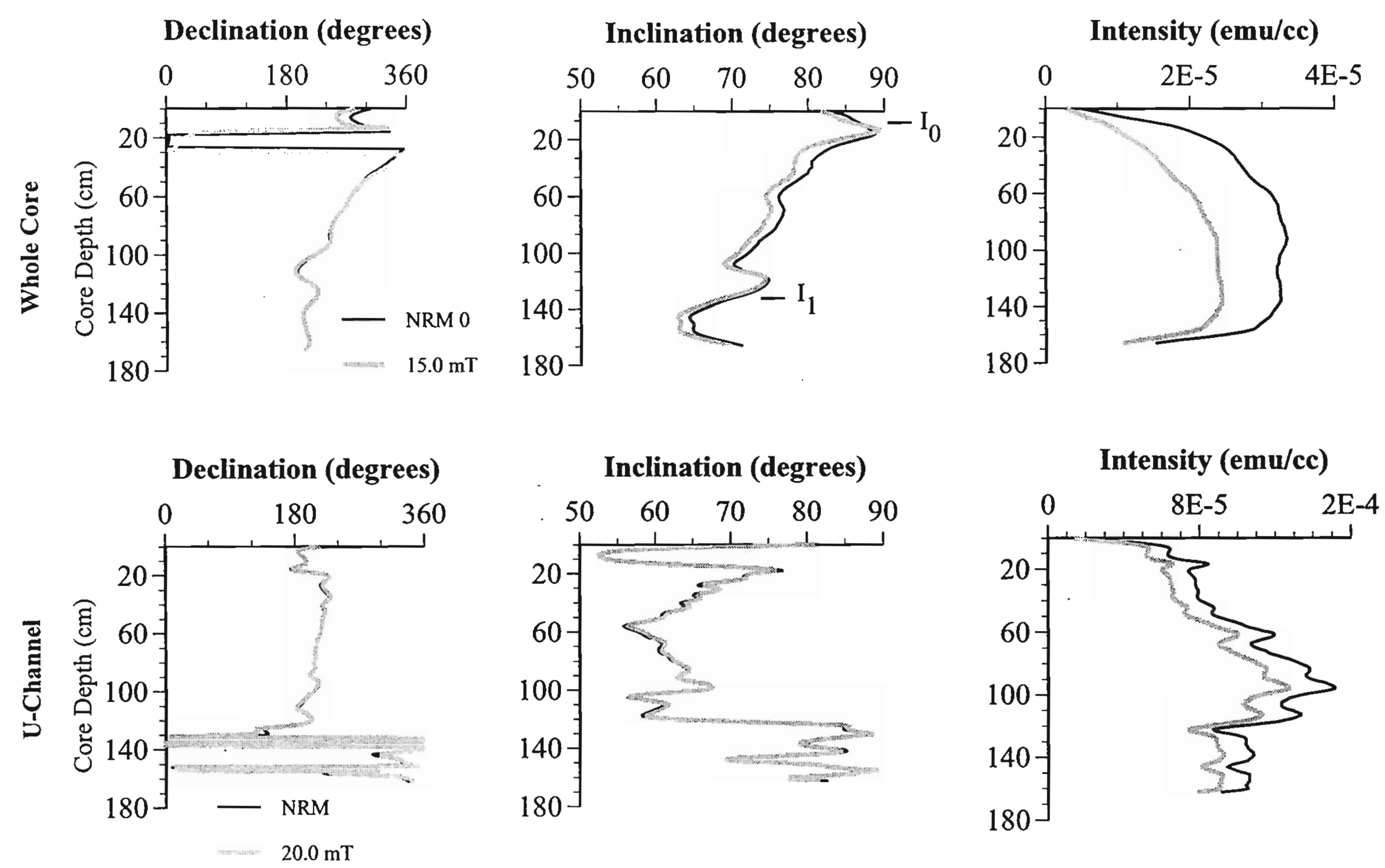

Figure 5. Down-core measurements of paleomagnetic properties for Lake Winnipeg 99-900 Core 4. Core break in U-channel data at 120.7 cm. Age diagnostic inclination features I_0 and I_1 are labelled for the whole core data.

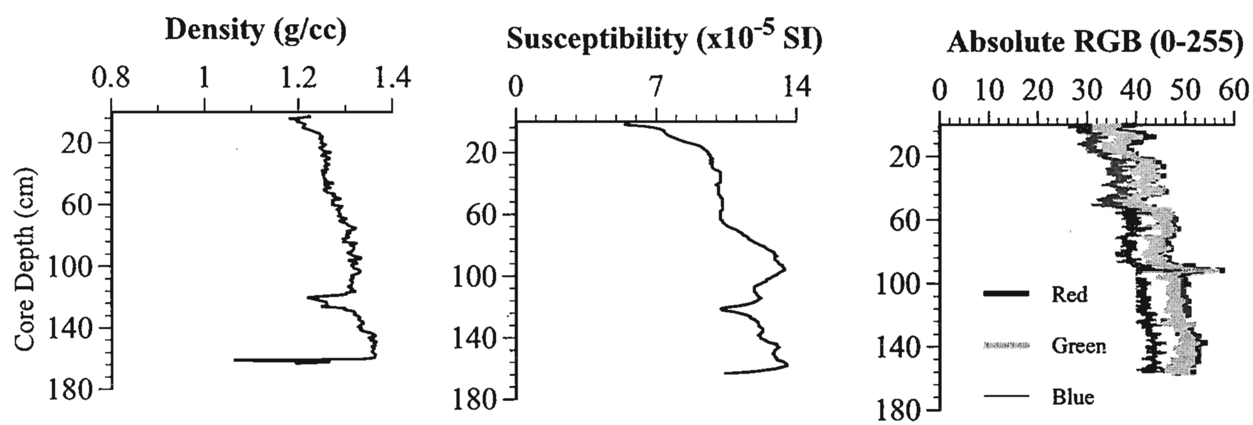

Figure 6. Down-core measurements of physical properties for Lake Winnipeg 99-900 Core 4. Core break at 120.7 cm.

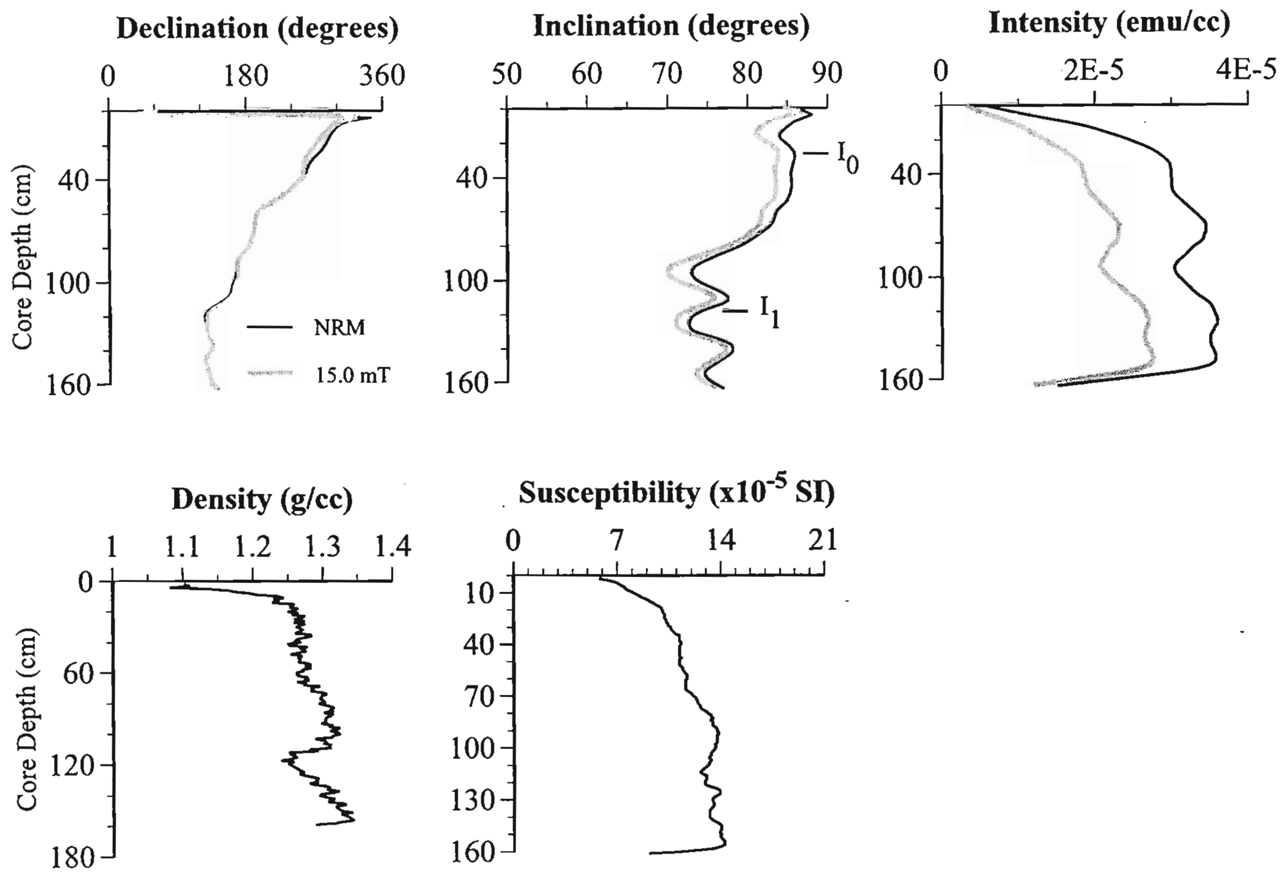

Figure 7. Down-core measurements of paleomagnetic and physical properties for Lake Winnipeg 99-900 Core 5. Core break at 120.6 cm in density and susceptibility data.

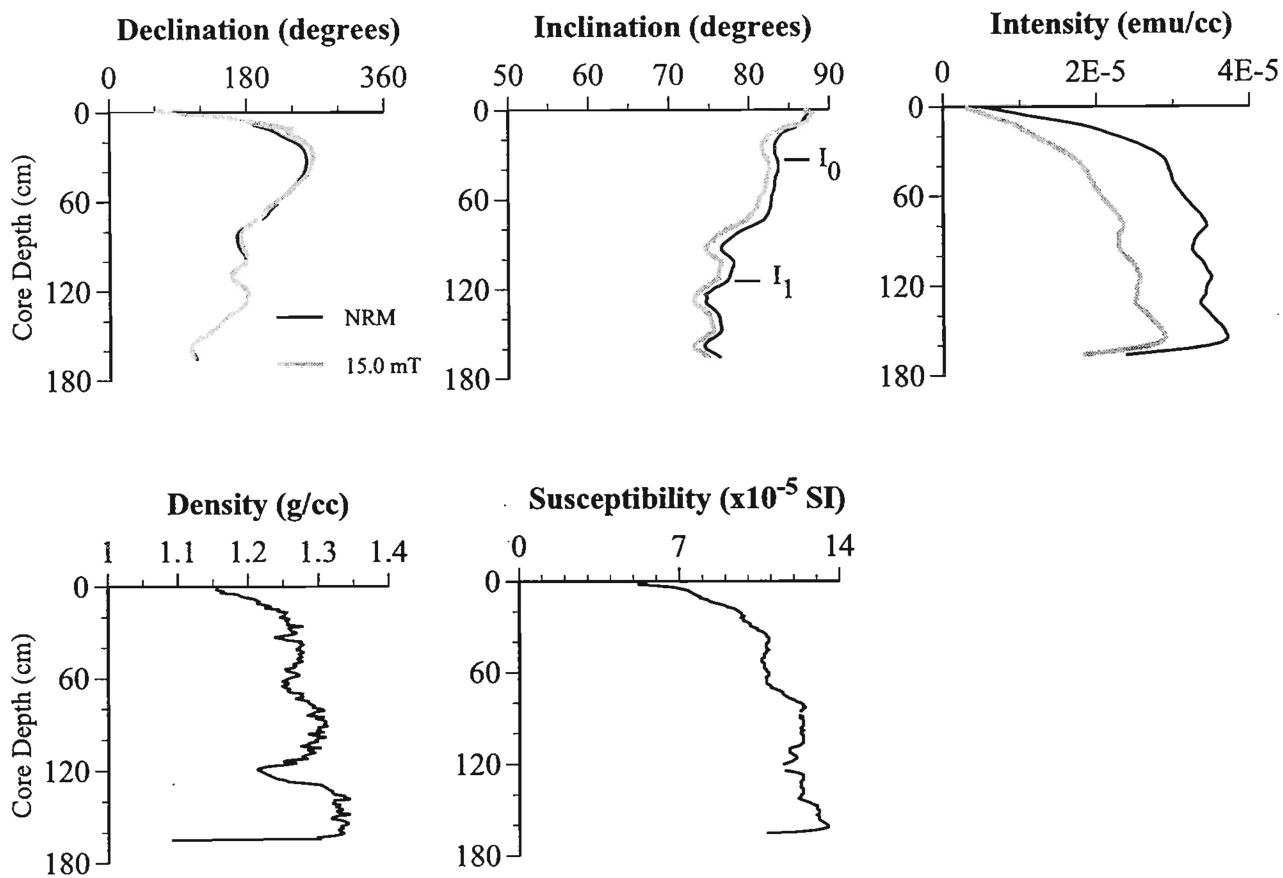

Figure 8. Down-core measurements of paleomagnetic and physical properties for Lake Winnipeg 99-900 Core 6. Core break at 121 cm in density and susceptibility data.

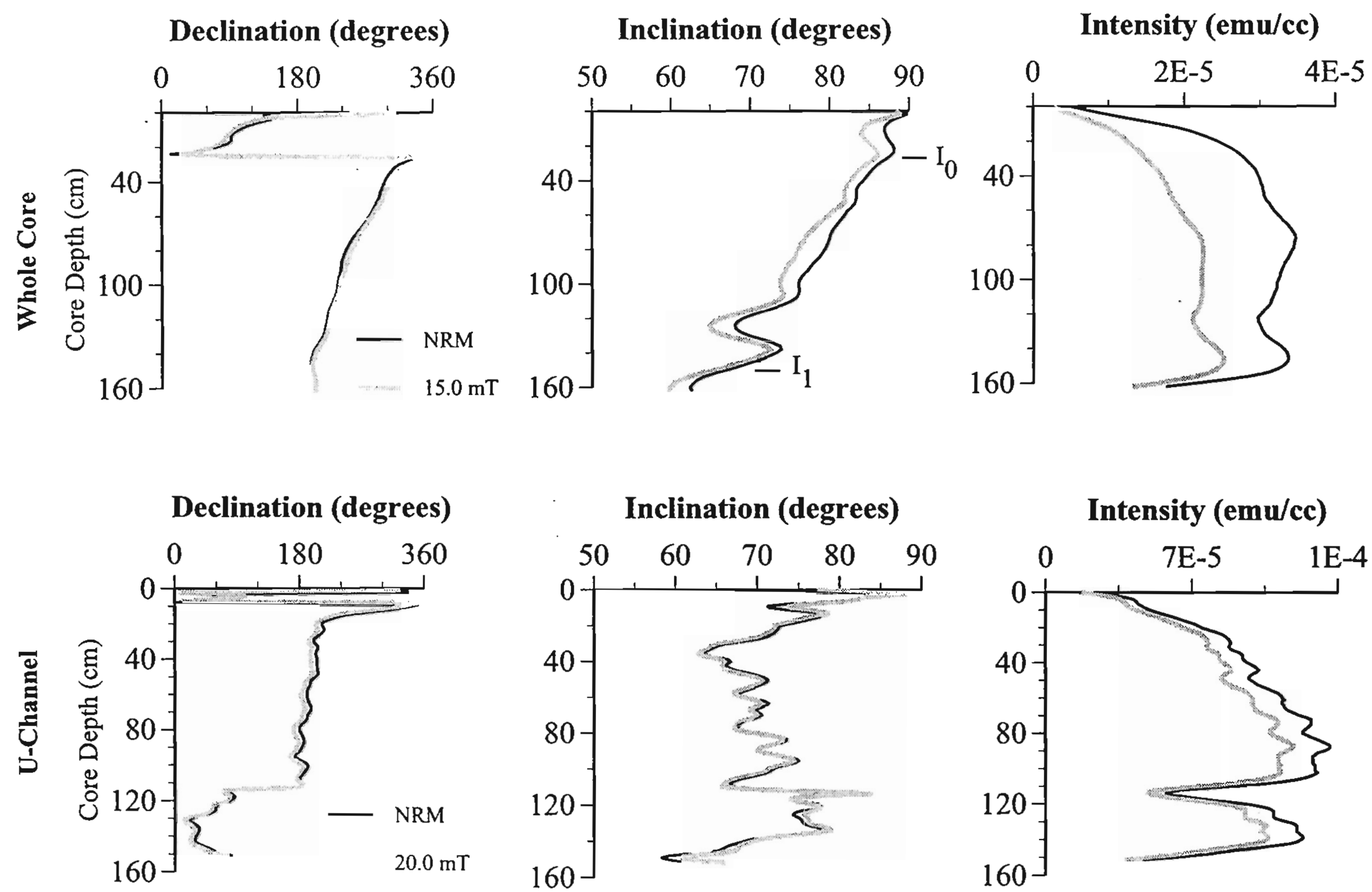

Figure 9. Down-core measurements of paleomagnetic properties for Lake Winnipeg 99-900 Core 7. Core break at 120.9 cm in U-channel data.

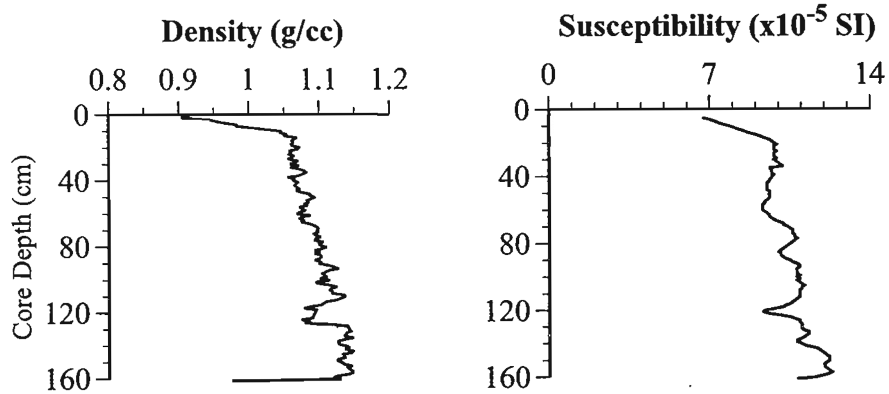

Figure 10. Down-core measurements of physical properties for Lake Winnipeg 99-900 Core 7. Core break at 120.9 cm.

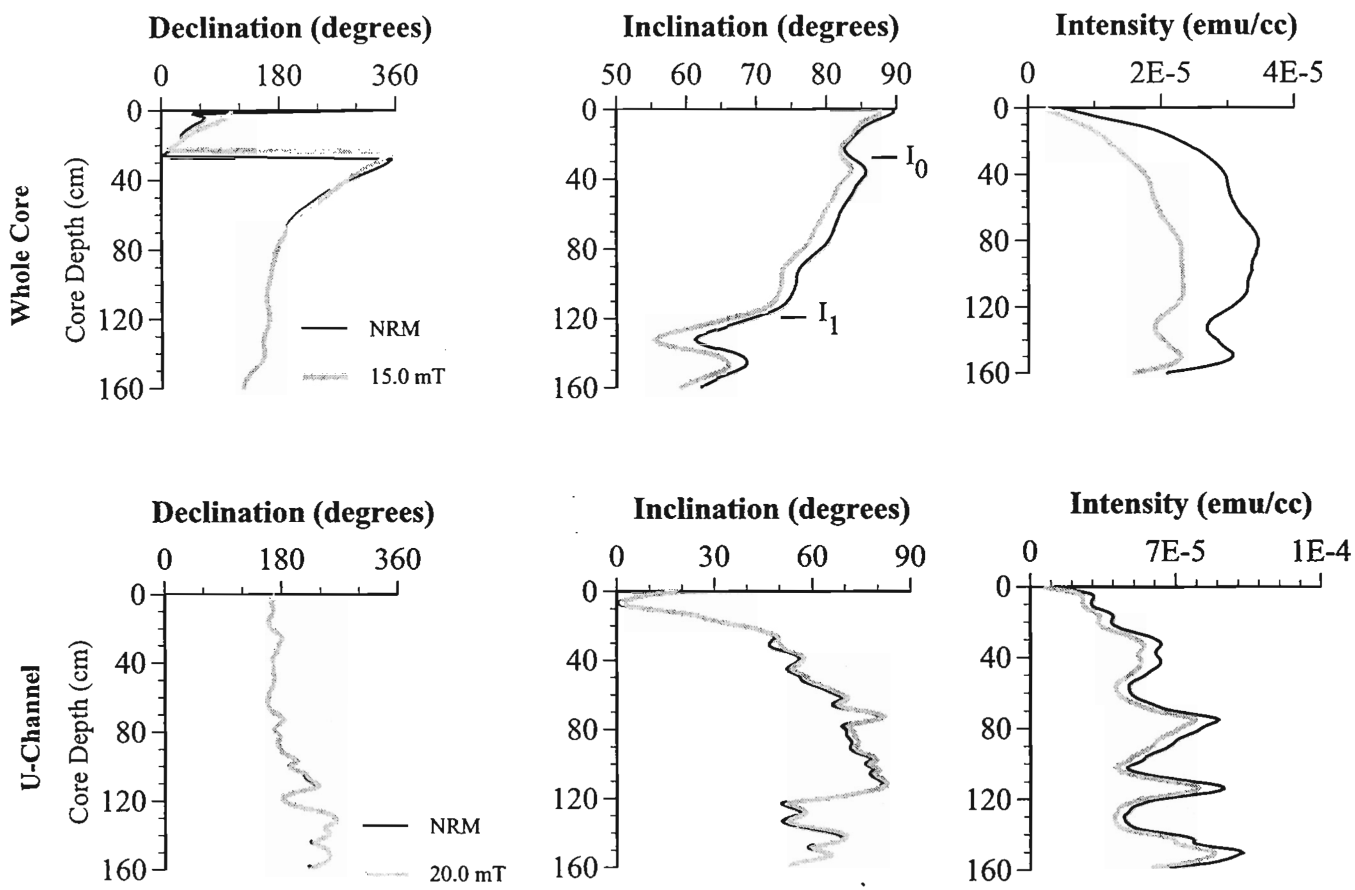

Figure 11. Down-core measurements of paleomagnetic properties for Lake Winnipeg 99-900 Core 8. Core break in U-channel data at 120.6 cm. Age diagnostic inclination features I_0 and I_1 are labelled for the whole core data.

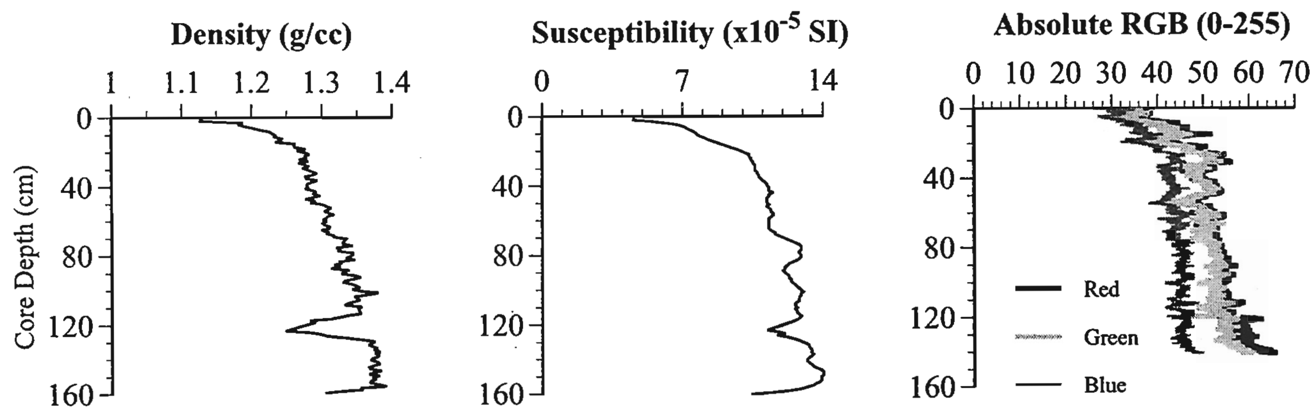

Figure 12. Down-core measurements of physical properties for Lake Winnipeg 99-900 Core 8. Core break at 120.6 cm.

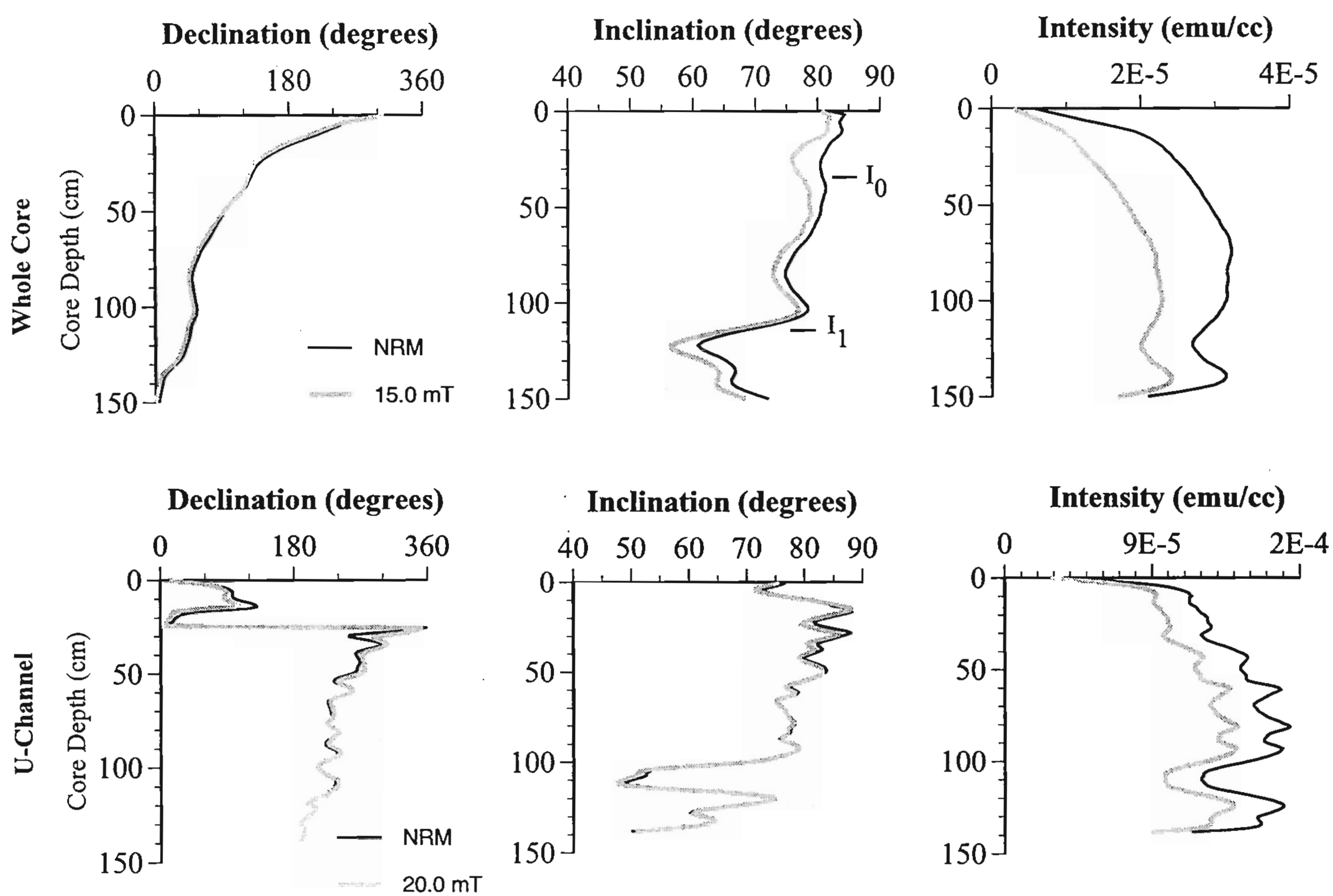

Figure 13. Down-core measurements of paleomagnetic properties for Lake Winnipeg 99-900 Core 9. Core break in U-channel data at 112 cm.

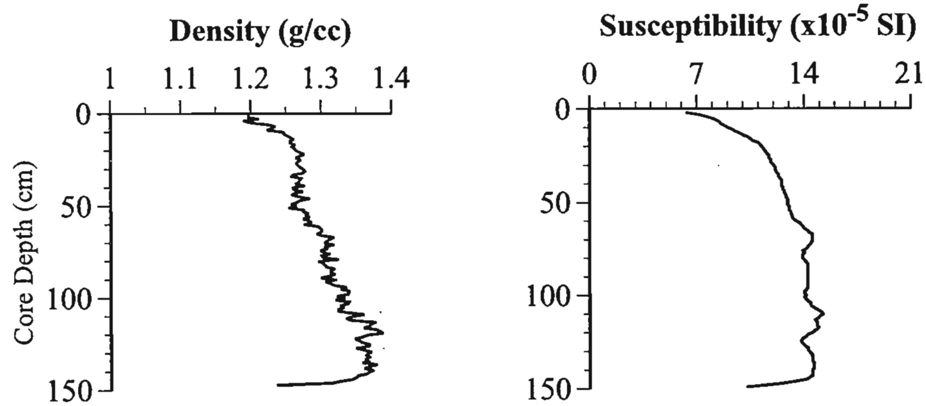

Figure 14. Down-core measurements of physical properties for Lake Winnipeg 99-900 Core 9. Core break at 112 cm.

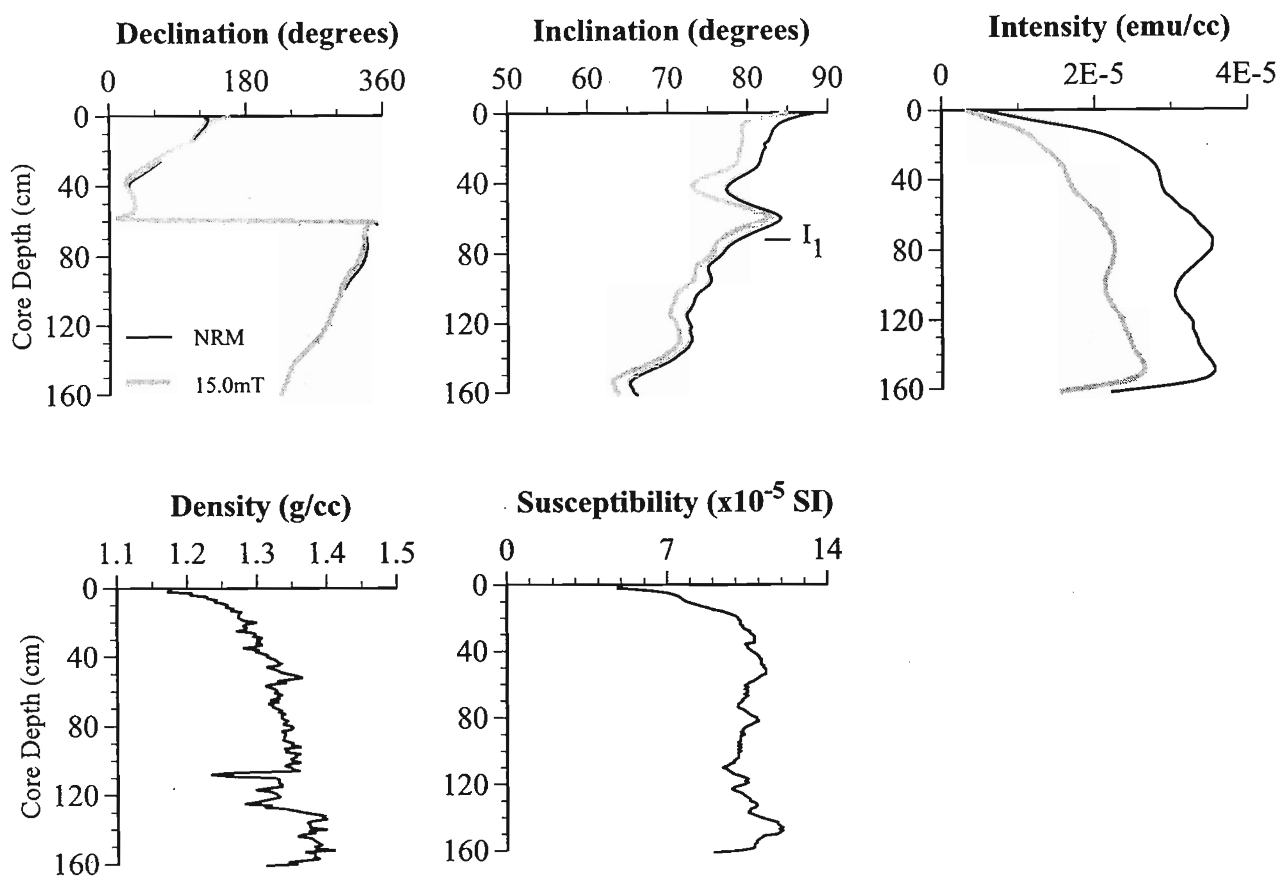

Figure 15. Down-core measurements of paleomagnetic and physical properties for Lake Winnipeg 99-900 Core 10 Core break at 121.1 cm in density and susceptibility data.

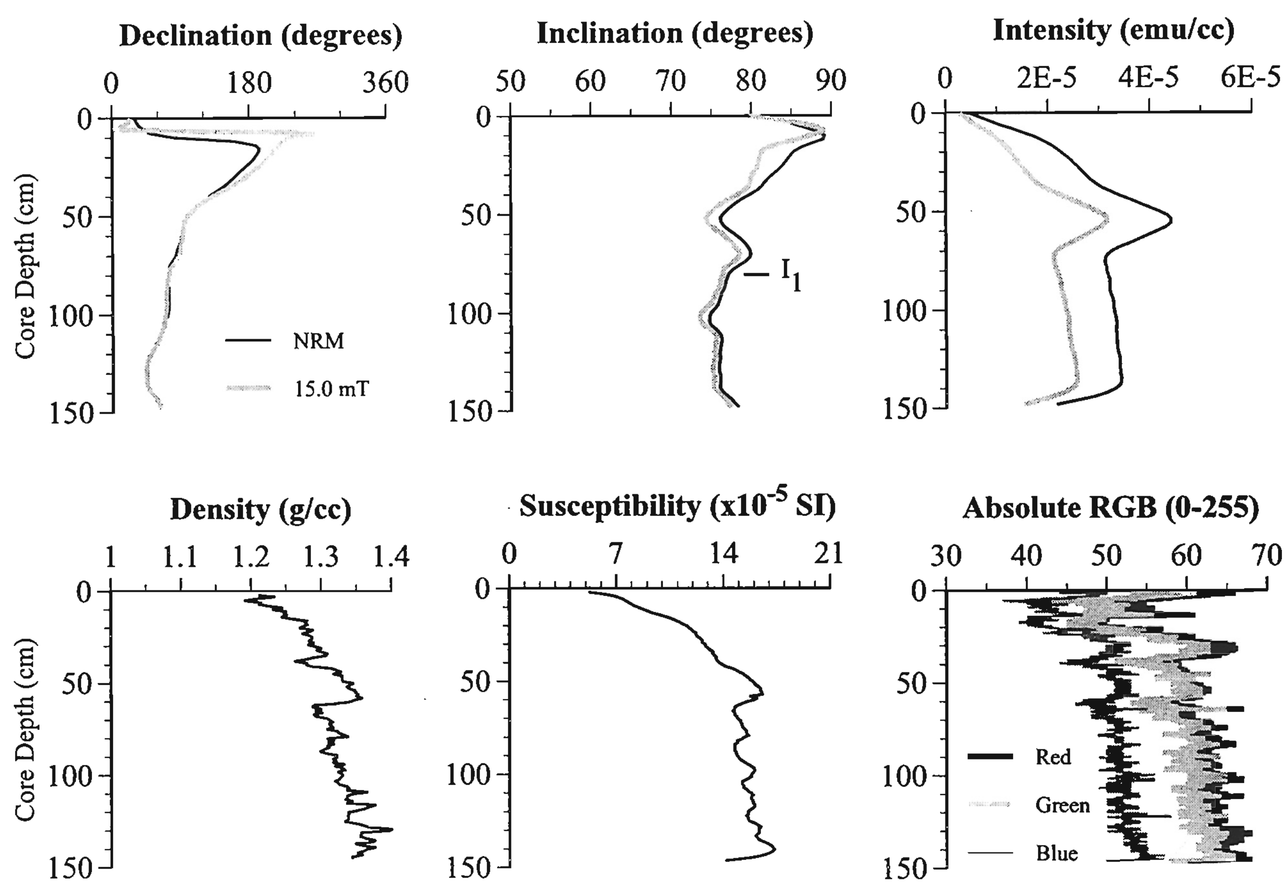

Figure 16. Down-core measurements of paleomagnetic and physical properties for Lake Winnipeg 99-900 Core 11.

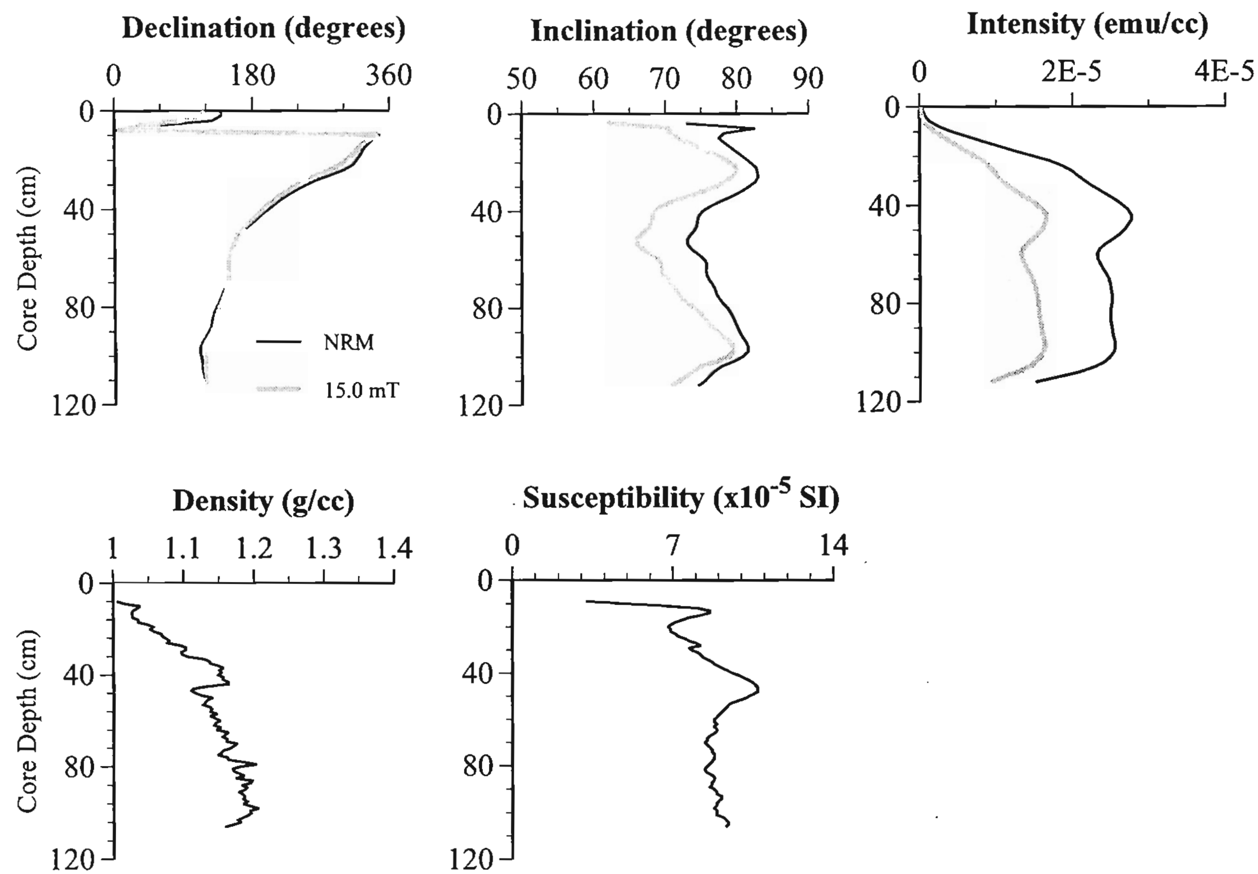

Figure 17. Down-core measurements of paleomagnetic and physical properties for Lake Winnipeg 99-900 Core 12.

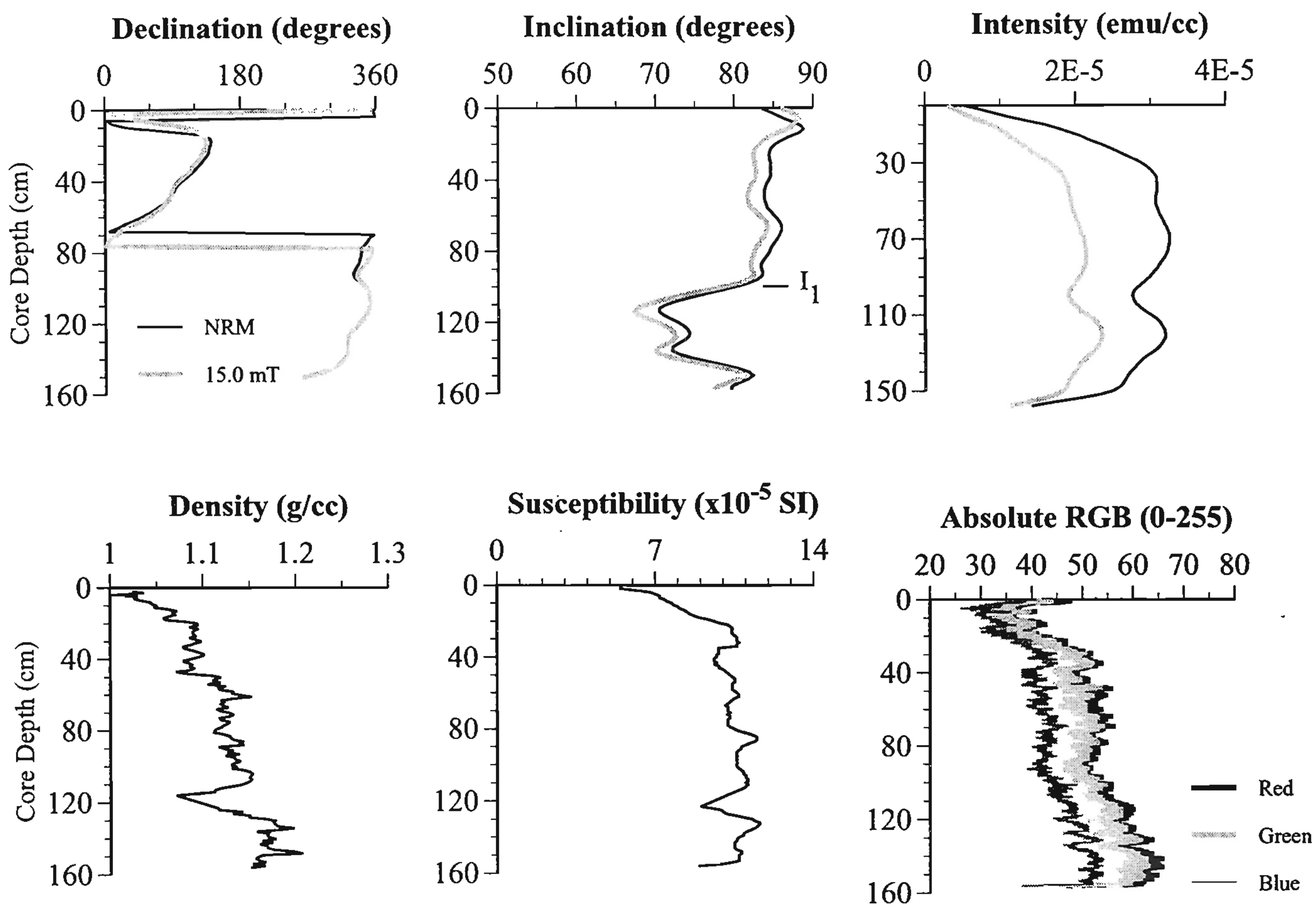

Figure 18. Down-core measurements of paleomagnetic and physical properties for Lake Winnipeg 99-900 Core 13. Core break at 120.7 cm in density, susceptibility, and RGB data.

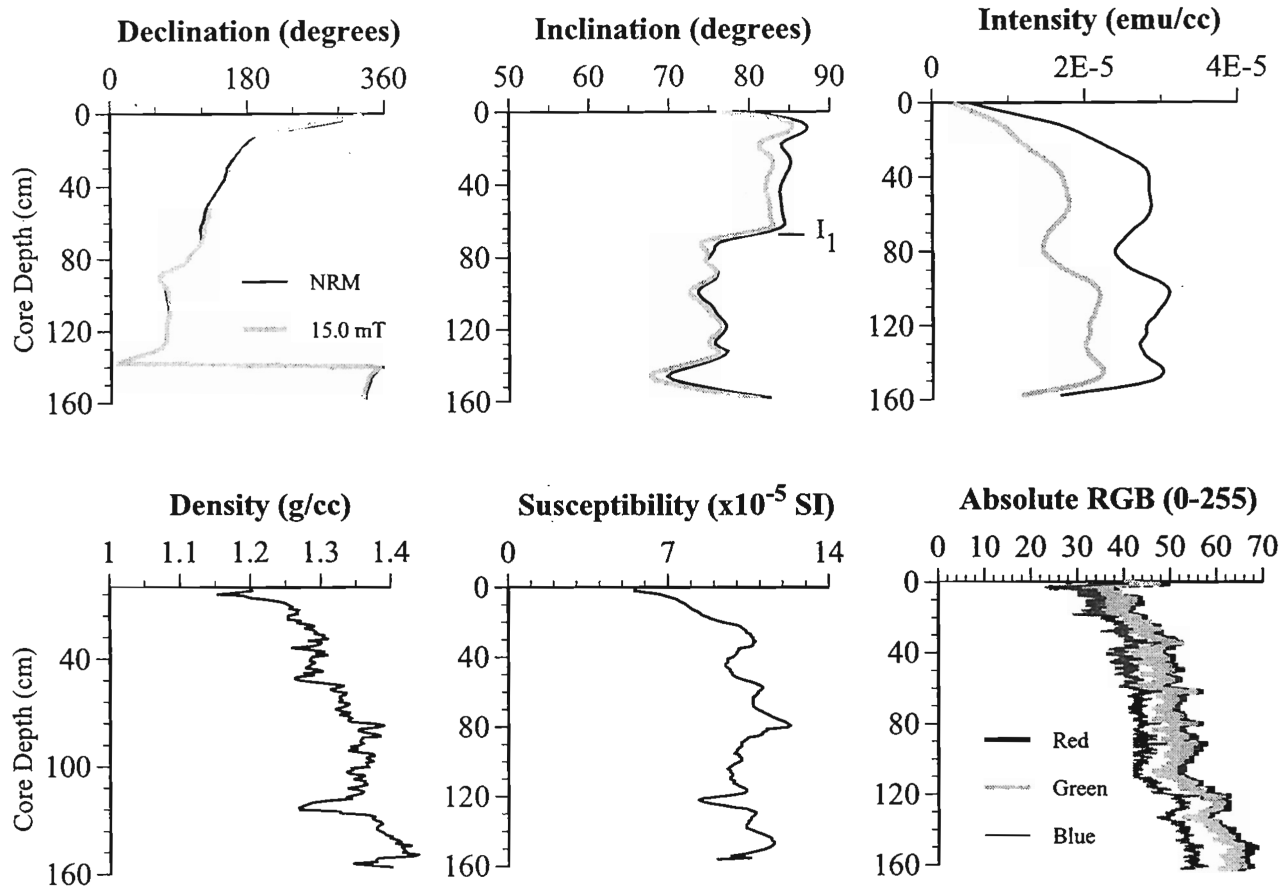

Figure 19. Down-core measurements of paleomagnetic and physical properties for Lake Winnipeg 99-900 Core 14. Core break at 120.5 cm in density, susceptibility, and RGB data.

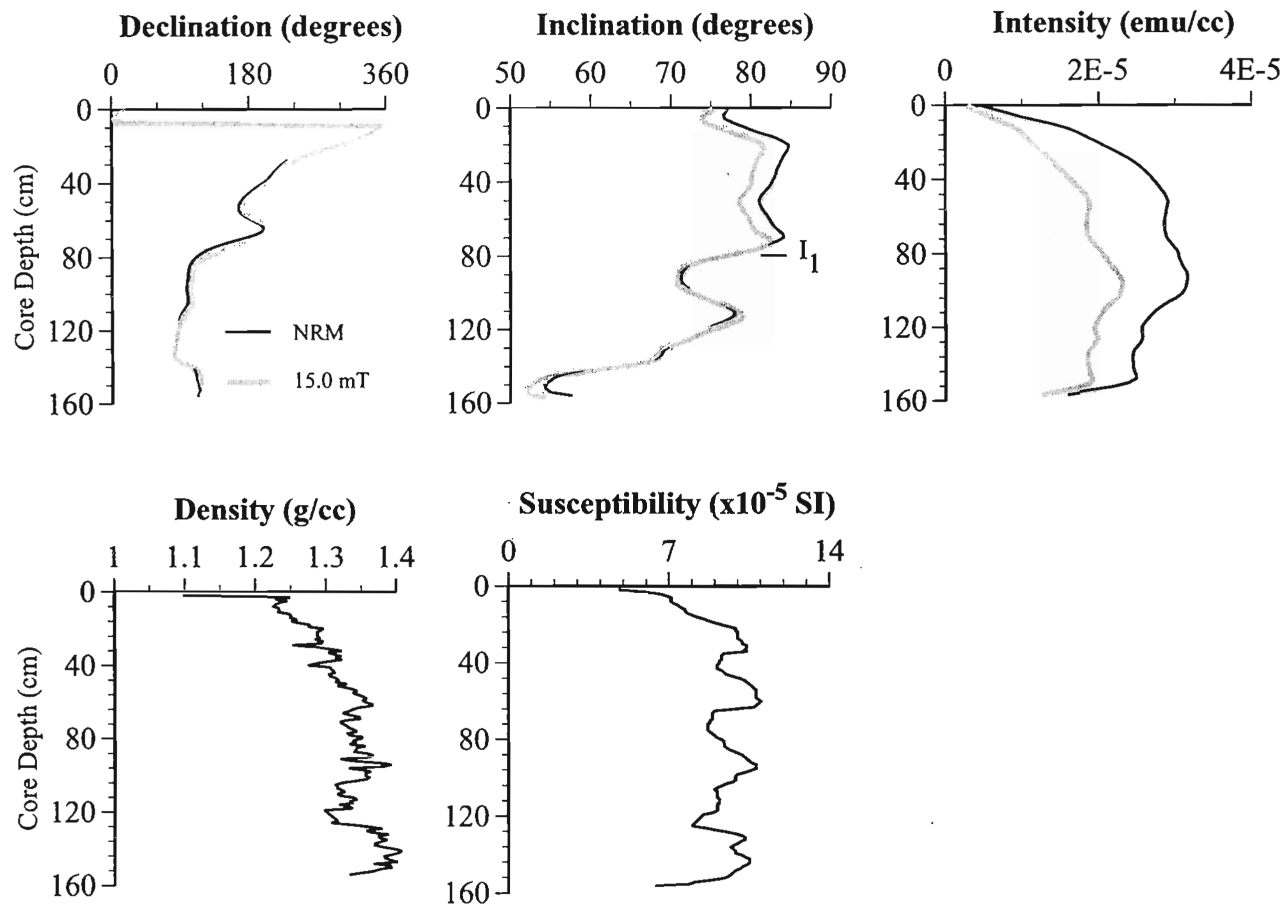

Figure 20. Down-core measurements of paleomagnetic and physical properties for Lake Winnipeg 99-900 Core 15. Core break at 120.7 cm in density and susceptibility data.

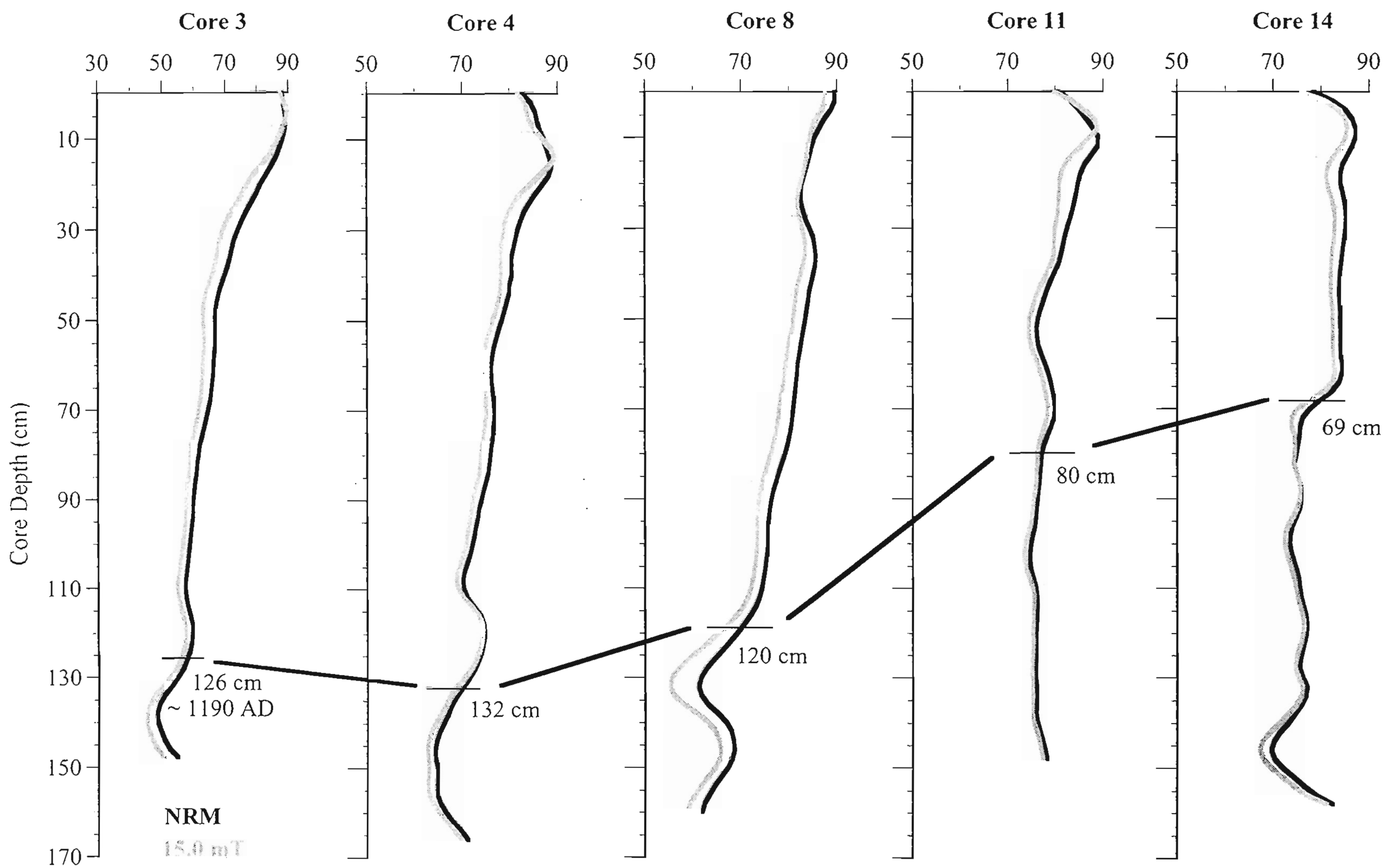

Figure 21. Paleomagnetic field inclination (degrees) for cores at the five sites sampled on a N-S transect in southern Lake Winnipeg.

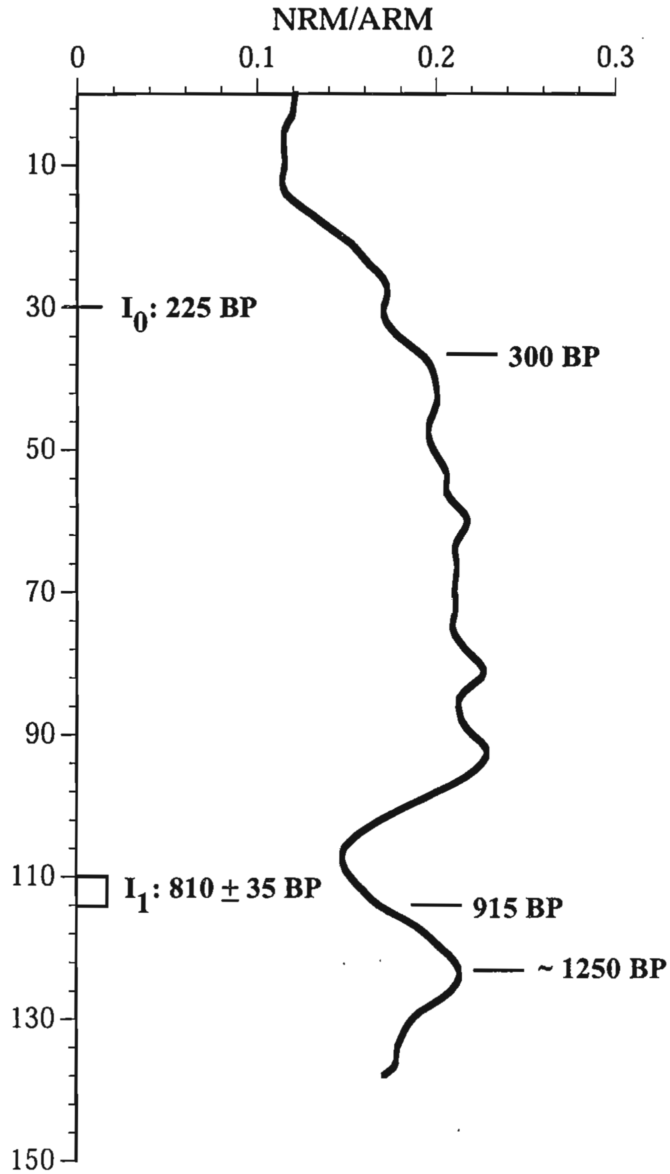

Figure 22. Relative paleointensity record for Lake Winnipeg 99-900 Core 9, estimated using the ratio of Natural Remanent Magnetization (NRM) to Anhysteretic Remanent Magnetization (ARM). The 300 and 1250 BP markers are age estimates obtained by comparison with the regional paleointensity curve from LeBoeuf Lake, Pennsylvania (King, et al, 1983).

4.2 Radiocarbon dating of Lake Winnipeg 99-900 core 9

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ABSTRACT

*[*] *Following the 1997 Red River flood, research addressing the history and controls on the flood hazard included analysis of sediments in Lake Winnipeg to assess flood history and drainage basin evolution. To do so, 15 cores, each about 1.5 m long, were collected from the south basin during a cruise of the Canadian Coast Guard Ship (CCGS) Namao in August 1999, designated Geological Survey of Canada (GSC) cruise 99-900.* Three cores were analyzed for macrofossils for the purpose of obtaining samples for radiocarbon dating, to provide chronology for the cored sediments. Two samples from one of the cores, insect remains from an individual aquatic insect, and the other a terrestrial wood fragment, were selected and submitted for radiocarbon dating. Previously, good chronological control was obtained from radiochemistry and pollen for the most recent 150 years, and a paleomagnetic inclination marker was identified lower in the cores. The samples therefore were selected from the lower portion of the core to provide a date for the I1 marker in Lake Winnipeg, and from the middle portion of the core to fill the gap where dates were not available. The insect material at 110-115 cm depth provided excellent corroboration at 810 ± 35 yrs BP (CAMS-84850). The rounded wood sample at 50-55 cm depth is interpreted as reworked, the wood being 2 to 3 centuries older than the enclosing sediment. Nevertheless, the analysis provides a useful maximum age of 475 ± 40 yrs BP (CAMS-84851).

INTRODUCTION

The Red River flood of 1997 was a major disaster that drove 103,000 people from their homes. Much is being done, however, to reduce comparable damage and disruption in the future through enhanced dikes and diversions, as well as revised land use and water management practices. The design of these works requires an optimal understanding of the risk. Research therefore has addressed the nature of the largest known flood, in 1826, whether comparable large floods have occurred in recent centuries, and how geomorphic, climatic, land use, and tectonic factors may be changing the flood hazard. These issues are being addressed by examining the geomorphic processes governing evolution of the Red River, archival records of flood history, floodplain stratigraphic records, tree-ring records, changes in valley gradients, and by examining the stratigraphy of Lake Winnipeg sediments (Thorleifson et al., 1998). The coring in Lake Winnipeg, receiving basin of waters from the Red River, was designed to sample sites most likely to have recorded any influx of sediments from the Red River that may have occurred. In addition to recording gradual changes in Red River sediment transport, it was thought that flood events might be recognizable, due to unique properties allowing differentiation from other sediments in the lake, although it was unclear what attribute would best distinguish flood-related sediments. The cores therefore were thoroughly analyzed for chronology, as well as for a broad range of physical, chemical and biological properties to determine which, if any, would record a history of flooding.

Three cores were analyzed for macrofossil content, for the purpose of obtaining suitable samples for radiocarbon age dating. Floral and faunal macrofossil profiles that provide paleoecological information on the depositional environment were also developed for the cores (Telka, this volume). A chronological model for the cores was developed using age determinations obtained by radiocarbon, Pb-210, Cs-137, palynological and paleomagnetic analyses (Wilkinson and Simpson, this volume).

LAKE WINNIPEG

Lake Winnipeg, located in central North America, is the eleventh largest lake in the world, having an area of 24,000 km^2 (Hutchinson, 1975). The lake straddles the contact between Paleozoic carbonate rocks to the west and Precambrian igneous and metamorphic rocks of the Canadian Shield to the east. A smaller south basin, approximately 90 km by 40 km, is separated from a north basin, approximately 240 km by 100 km, by a narrow passage known as The Narrows. The glacially-scoured depression in the rocks underlying the lake, with a depth of 50-100 m, is largely filled with fine-grained glacial Lake Agassiz sediments, overlain by up to 15 m of post-glacial Lake Winnipeg sediments (Todd and Lewis, 1996). The bathymetry of the lake is shallow and the bottom is flat, with depths averaging 9 m in the south basin and 16 m in the north basin. The lake has a catchment area extending from the Rocky Mountains to very near Lake Superior, including the basins of the Winnipeg, Saskatchewan, Red, Dauphin and numerous smaller rivers. Outflow from the lake is north to Hudson Bay, through the Nelson River. Post-glacial uplift has caused the north end of the basin to

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rise relative to the south, causing a gradual rise of lake levels that continues at present (Lewis et al., 2000). The mean annual temperature of the region, recorded at Gimli, is +1.4°C, although the continental climate of the region ranges from hot summers to very cold winters. The mean annual precipitation is 50.8 cm. The lake is ice free from early May to late November (Ice Thickness Climatology, 1992) and ice cover from November to May is consistently thick and continuous. The lake waters are poorly stratified to unstratified and during the summer months water temperatures range from +17°C in the north basin to +19.5°C in the south basin (Todd, 1996), hence bottom sediment temperatures are equally warm in mid-summer. The lake supports a commercial fishery, it is a major destination for recreation, and lake levels are regulated to optimize hydroelectric power generation on the Nelson River.

SAMPLING AND ANALYTICAL METHODS

Selection of five sampling sites in the south basin of Lake Winnipeg was based on proximity to the Red River mouth and on the absence of ice scour on sidescan sonar records previously obtained on the 94-900 Namao cruise (Lewis et al., this volume) (Figure 1). Site 5 was the southernmost point on the north-south survey line that lacked ice scour. Sampling was conducted in calm weather on August 24, 1999 from the CCGS Namao. Three cores were obtained at each of the five sites using a gravity corer consisting of a 100 kg weightstand over a 2 m steel pipe with a 10 cm diameter plastic liner tube. The length of the cores ranged from 107 cm to 170 cm. The cores were sealed, labelled and transported to Gimli, Manitoba on August 29, where they were refrigerated, and subsequently transported via refrigerated truck to the GSC core storage facility in Dartmouth, N.S. A monitoring device attached to the core bundle indicated that the sediments did not exceed a temperature of 19°C at any time during transport. Paleomagnetic and physical property data, determined at the laboratory of Professor J.W. King at the University of Rhode Island, provided information used to select cores that would be representative of the offshore sediments (King et al., this volume). Paleomagnetic profiles indicated more rapid accumulation of sediments at the more northerly sites and hence a higher resolution for examining environmental change. Based on these observations, core 8 (site 3), core 4 (site 2), and core 3 (site 1) were selected as the primary records for detailed study.

Because macrofossils are rare in these sediments, a large amount of material was required for macrofossil recovery, hence nearby cores were selected for this purpose. Cores 5, 7, and later 9 were selected on the basis of proximity to the primary cores, good paleomagnetic profiles indicating intact stratigraphy and good correlation of paleomagnetic records for cores 7 and 9 with that of the well-dated core 8. Initially, cores 5 and 7 were selected for macrofossil analysis. However, insufficient material was sampled from core 5 and subsequently a section of the core was found to be missing, thus prohibiting re-sampling. Due to a labelling error with core 7, a very young sample was sent for radiocarbon dating (CAMS-71707) and did not provide a useful age determination (modern). Between 1 and 5 cm of material from the top of core 7 was inadvertently mixed with deeper sediments due to a core labelling error. Analysis of this interval therefore was disregarded. Upon recognition of the error, it was concluded that no appropriate macrofossils were available elsewhere in the core. Core 9 was then analyzed in the hope of obtaining mid-core to lower-core samples for radiocarbon dating.

The working halves of the cores were subsampled at GSC facilities in Dartmouth in 5-cm slices. A total of 22, 29 and 28 samples were obtained from cores 5, 7 and 9, respectively. Each sample, ranging from 100 to 200 mL (wet) in volume, was placed in a sealed plastic bag.

Macrofossil preparation and selection of samples for dating were performed by the author. Initially the samples were weighed and the volumes approximated using a water displacement technique. Using warm tap water, the remaining sediment was gently sieved through nested 40, 60 and 230 mesh Canadian Standard Series sieves (mesh openings of 0.425 mm, 0.25 mm and 0.063 mm respectively). The sieved residue greater than 0.25 mm was examined using a binocular microscope, and plant and animal fossil remains were isolated for identification and potential radiocarbon dating. Macrofossils suitable for radiocarbon dating were identified and their preservation noted with the aid of the microscope. To eliminate any sources of contamination from biological growth, the selected macrofossils were air dried, weighed and stored in pre-rinsed, clean glass vials prior to submission for dating.

Selection of samples for Accelerator Mass Spectrometry (AMS) radiocarbon dating was based on several considerations, with the aim of minimizing incorporation of reworked material and to select only taxa that sequester atmospheric carbon. The degree of reworking can be estimated from signs of wear. Plant macrofossils with negligible or minimal signs of wear had likely been deposited close to their source, such that only minimal transport and reworking had occurred. Selection of taxa that utilize only atmospheric carbon was based on knowledge of the life habits of the examined taxa. For example, both larvae and adults of the aquatic water scavenger beetle (Hydrophilidae) are atmospheric breathers and must continuously return to the surface of the water to renew their air supply. This is accomplished through reliance on self-contained air reserves, which are carried between the elytra and abdomen. In addition, hydrophilids have short, dense hydrofuge pubescence on the underside of their bodies, enabling them to hold a film of air in connection with the elytral reservoirs. A further consideration was to obtain samples mid-core, in order to obtain dates for the interval not dated by other means.

Although attempts were made to select macrofossils for dating based on the considerations outlined above, selection was controlled by the very limited abundance of macrofossil specimens (Telka, this volume). Given these considerations, a sample consisting of dandelion and thistle seeds from core 7 was initially submitted. Subsequently, two samples from core 9, the first, insect remains of an aquatic beetle, and the second, a somewhat worn terrestrial wood fragment, were submitted for radiocarbon dating.

Radiocarbon analysis was performed at the Center for Accelerator Mass Spectrometry (CAMS), Lawrence Livermore National Laboratory at the University of California. Compared to conventional radiocarbon dating, the AMS ^{14}C technique has the advantage of dating small samples and the CAMS lab in particular is able to analyze small samples (minimum 0.5 mg) with high precision.

RESULTS

Radiocarbon dates and related information for samples obtained from cores 7 and 9 are presented in Table 1. The data table includes the core number, the depth (in cm) of the sampling interval below the top of the core, the age in radiocarbon years, the possible calibrated ages, the taxon, the habitat designation, and the degree of preservation. As the core was analyzed in 5-cm increments, the depth of macrofossil identification is estimated as the mid-point of the interval. Results were converted from radiocarbon to one or several possible calendar ages using CALIB4.1 (Stuiver and Reimer, 1993). Habitat designations included aquatic/shoreline taxa and terrestrial taxa. A statement of excellent preservation denotes the presence of delicate features, such as intact, fragile ornamentation, while fair preservation indicates that only traces of these features remain.

Calibration of radiocarbon dates

Radiocarbon ages were calibrated in order to provide dates in calendar years (years AD) for use in developing a chronological model for the cored sediments. The specific activity of ^{14}C in atmospheric CO_2 has varied (e.g. Stuiver and Braziunas, 1993). This variation has been modeled by measurement of the radiocarbon age of tree rings of known age (determined by dendrochronological means) and has allowed for the development of decadal calibration datasets used for conversion of radiocarbon to calibrated ages. Linear interpolation of the data points of the calibration dataset is used to create calibration curves of calibrated age (x-axis) versus radiocarbon age (y-axis). CALIB4.1 (Stuiver and Reimer, 1993) was used to make this conversion and to calculate the probability distribution of the sample's true age.

Calibrated ages were determined using the "intercepts with curve" method, in which ages are given by the intercept of the calibration curve with the radiocarbon age (Stuiver and Reimer, 1993). With this method, multiple intercepts, and hence multiple ages are possible. The two sigma (2σ) errors or 95 % confidence levels are determined from the intersection of the calibration curve with the ±2SD values (two times the standard deviation) of the radiocarbon age. The sample consisting of insect material produced three possible calibrated ages, while the wood fragment produced only one (Table 1). The 2σ age ranges for the insect material is AD 1160-1280, while that of the wood is AD 1400-1480 (Table 1).

DISCUSSION

The two macrofossil samples obtained from core 9 for radiocarbon analysis provided two calibrated age dates in the early- to mid-millennial age range. The age of the wood fragment was older than the age implied by interpolation from other data. Given its slightly worn appearance and rounded edges, it had likely been transported some distance prior to its incorporation in Lake Winnipeg sediments. Hence, there could be a gap from the time the tree ceased living to the time it was deposited in the Lake, and the calibrated age is best described as a maximum age.

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Table 1. Radiocarbon dates obtained for Lake Winnipeg 99-900 samples

Core No. and Depth (cm)	Lab No.	Radiocarbon Age (yrs BP)	Possible Calibrated* Age (yrs AD)	Taxon	Habitat Designation	Preservation
Core 7-5-15cm	CAMS-71707	Modern	n/a	Thistle and dandelion seeds	Terrestrial	Excellent
Core-9-110-115cm	CAMS-84850	810 ± 35	1220, 1230, 1240 (1160-1280)	Water scavenger beetle (Hydrophilidae) elytra and misc. parts (metasternum, sternites,etc.)	Aquatic/shoreline	Excellent
Core-9-50-55cm	CAMS-84851	475 ± 40	1440 (1400-1480)	Wood fragment	Terrestrial	Fair - no outer bark, ends slightly rounded

*Calibrated using CALIB4.1 software by Stuiver and Reimer (1993). The first set of values are the possible calibrated ages, while the values in brackets are the (2 sigma) minimum and maximum ages. Values have been rounded to the nearest decade.

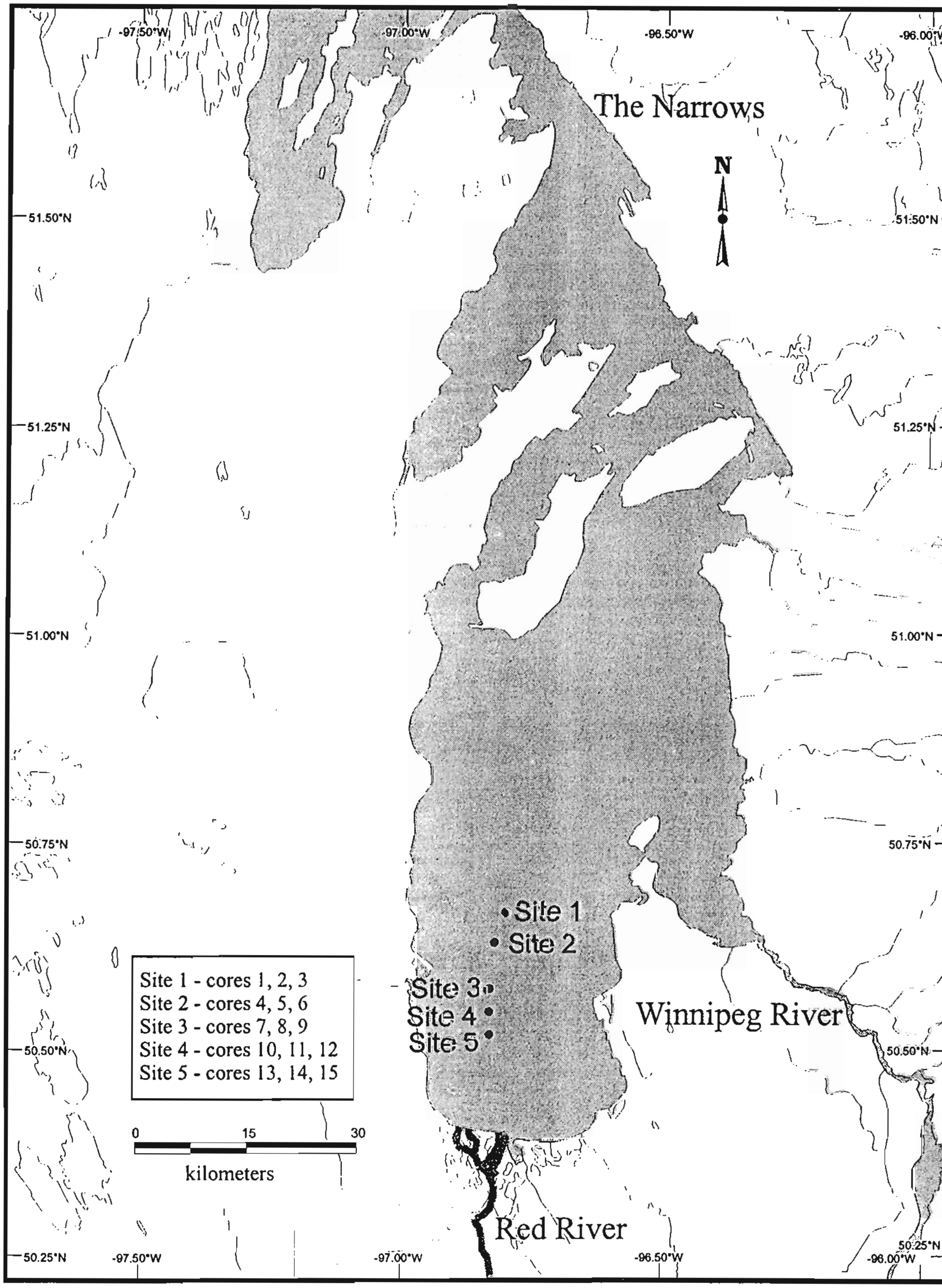

Figure 1. Map of southern Lake Winnipeg showing locations of coring sites

4.3 Radiochemical analysis of Lake Winnipeg 99-900 cores 4 and 8

P. Wilkinson[1] and S.L. Simpson[2]

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ABSTRACT

**Following the 1997 Red River flood, research addressing the history and controls on the flood hazard included analysis of sediments in Lake Winnipeg to assess flood history and drainage basin evolution. To do so, 15 cores, each about 1.5 m long, were collected from the south basin during a cruise of the Canadian Coast Guard Ship (CCGS) Namao in August 1999, designated Geological Survey of Canada (GSC) cruise 99-900.* Two cores were sliced into 1-cm sections and analyzed radiochemically to obtain ages and sedimentation rates for the past 150 years. These dates, as well as those obtained using palynological, paleomagnetic and radiocarbon analyses were used to establish a chronology for the cored sediments. Lead-210 ages were determined from unsupported Pb-210 activity, using the Constant Rate of Supply (CRS) method, for the upper 34-35 cm of the cores. The results indicate an age of AD 1900 at ~25-26 cm depth in core 4 and ~27-28 cm in core 8. The peak Cs-137 activity in the cores, at depths of 12-13 cm in core 4 and 13-14 cm in core 8, was attributed to the period of peak fallout from nuclear bomb testing. This peak occurs in the mid 1960's as a result of the signing of the Limited Test Ban Treaty in 1963, which banned atmospheric testing of nuclear devices. The integrity of the Pb-210 dates is confirmed by peak Cs-137 in the mid 1960's. A second Cs-137 peak of lesser magnitude is dated from Pb-210 results at 1985 (6-7 cm) in core 4 and 1984 (7-8 cm) in core 8. This second peak is attributed to contamination of the basin, likely from a documented spill that occurred at the Whiteshell Nuclear Research Establishment in 1979, on the Winnipeg River. The occurrence of Cs-137 in the cores below 1952 levels is likely the result of slight smearing during coring. Average sedimentation rates for the measured interval, using the CRS method, were higher for core 8 (861 $g/m^2/yr$) than for core 4 (635 $g/m^2/yr$). Up-core increases in sedimentation rates were observed in both cores. The post-1850 chronology is augmented with a *Salsola* pollen marker, and the pre-1850 chronology is based on linear interpolation between the lowest Pb-210 date and the paleomagnetic inclination marker I1. Sedimentation rates shift from an average of 1.3-1.5 mm/yr in the pre-1900 period to an average of 2.6 mm/yr post-1900.

* Italicized text is repeated in each chapter

INTRODUCTION

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Two cores were analyzed radiochemically for Pb-210 and Cs-137 to establish chronology of the uppermost portion of the cored sediments and to determine sedimentation rates for this interval. A chronological model for the cores is developed here using age determinations obtained by radiocarbon, Pb-210, Cs-137, palynological and paleomagnetic analyses.

LAKE WINNIPEG

Lake Winnipeg, located in central North America, is the eleventh largest lake in the world, having an area of 24,000 km^2 (Hutchinson, 1975). The lake straddles the contact between Paleozoic carbonate rocks to the west and Precambrian igneous and metamorphic rocks of the Canadian Shield to the east. A smaller south basin, *approximately 90 km by 40 km, is separated from a north basin, approximately 240 km by 100 km, by a narrow passage known as The Narrows. The glacially-scoured depression in the rocks underlying the lake, with a depth of 50-100 m, is largely filled with fine-grained glacial Lake Agassiz sediments, overlain by up to 15 m of post-glacial Lake Winnipeg sediments (Todd and Lewis, 1996). The bathymetry of the lake is shallow and the bottom is flat, with depths averaging 9 m in the south basin and 16 m in the north basin. The lake has a catchment area extending from the Rocky Mountains to very near Lake Superior, including the basins of the Winnipeg, Saskatchewan, Red, Dauphin and numerous smaller rivers. Outflow from the lake is north to Hudson Bay, through the Nelson River. Post-glacial uplift has caused the north end of the basin to rise relative to the south, causing a gradual rise of lake levels that continues at present (Lewis et al., 2000). The mean annual temperature of the region, recorded at Gimli, is +1.4°C, although the continental climate of the region ranges from hot summers to very cold winters. The mean annual precipitation is 50.8 cm. The lake is ice free from early May to late November (Ice Thickness Climatology, 1992) and ice cover from November to May is consistently thick and continuous. The lake waters are poorly stratified to unstratified and during the summer months water temperatures range from +17°C in the north basin to +19.5°C in the south basin (Todd, 1996), hence bottom sediment temperatures are equally warm in mid-summer. The lake supports a commercial fishery, it is a major destination for recreation, and lake levels are regulated to optimize hydroelectric power generation on the Nelson River.*

THEORETICAL INTRODUCTION

Lead-210 is a member of the U-238 decay series. One of the decay products of U-238 is Ra-226, which exists in most rocks, soils and sediments. Radium-226 decays to Rn-222, which is a gas and can escape to the atmosphere. Radon-222 decays rapidly (half life = 3.8 days) through a series of short-lived daughters to Pb-210, which adsorbs onto atmospheric particulates that are removed from the atmosphere by rain, snow or dryfall. This atmospheric input of Pb-210 is incorporated in lake sediments as 'excess' or 'unsupported' Pb-210 as it is not associated with it's parent, Ra-226. The activity (concentration) of Pb-210 decreases as a function of time (half life = 22.26 years) and permits age determinations of certain geological materials deposited within the past 100-130 years (Goldberg, 1963). If no sediment mixing occurs and the sediment accumulation rate is constant, the decay of Pb-210 activity downcore is exponential, reaching a value that is referred to as 'supported' activity. Supported Pb-210 is formed *in situ* from the decay of Ra-226. Lead-210 dates are determined solely from the 'unsupported' Pb-210 activity derived from external and atmospheric sources, and is calculated by subtracting supported activity (measured Ra-226 activity) from the total measured Pb-210 activity in each slice.

Lead-210 dating is modelled here by means of the Constant Rate of Supply (CRS) model, which assumes a constant flux of Pb-210 to the sediment surface (Goldberg, 1963; Appleby and Oldfield, 1978; Robbins, 1978). The CRS method assumes that the amount of Pb-210 supplied is independent of the sedimentary accumulation rate, such that if the accumulation rate changes, only the activity of Pb-210 in the sediments will change.

Age, expressed in years, is calculated from

$$T_x = [\ln(A_O/A_X)]/k \qquad (1)$$

where k is the decay constant for Pb-210 (0.03114/yr), A_O is the total integrated, unsupported Pb-210 activity (Bq/cm^{-2}) in the core and A_X is the integrated activity of unsupported Pb-210 activity (Bq/cm^{-2}) below depth x.

The sedimentation rate (r) is calculated from

$$r = m/T \qquad (2)$$

where m is the total mass per unit area of the core section and T is calculated as the age difference between the upper and lower limit of the core section (Sanchez-Cabeza, 2000).

Errors in T_x and r were calculated using standard propagation of error formulas for each mathematical operation in the model (Friedlander, 1981). These errors are derived from uncertainties in the counting statistics in the determination of the absolute activities of Pb-210 and Ra-226 and from the 'assigned' (Appleby, 2002) errors of 5 % used for the errors in weighing and determination of slice mass per unit area. No error estimates are used to describe coring artefacts or unaccountable loss of material during storage and slicing.

SAMPLING AND ANALYTICAL METHODS

Selection of five sampling sites in the south basin of Lake Winnipeg was based on proximity to the Red River mouth and on the absence of ice scour on sidescan sonar records previously obtained on the 94-900 Namao cruise (Lewis et al., this volume) (Figure 1). Site 5 was the southernmost point on the north-south survey line that lacked ice scour. Sampling was conducted in calm weather on August 24, 1999 from the CCGS Namao. Three cores were obtained at each of the five sites using a gravity corer consisting of a 100 kg weightstand over a 2 m steel pipe with a 10 cm diameter plastic liner tube. The length of the cores ranged from 107 cm to 170 cm. The cores were sealed, labelled and transported to Gimli, Manitoba on August 29, where they were refrigerated, and subsequently transported via refrigerated truck to the GSC core storage facility in Dartmouth, N.S. A monitoring device attached to the core bundle indicated that the sediments did not exceed a temperature of 19°C at any time during transport. Paleomagnetic and physical property data, determined at the laboratory of Professor J.W. King at the University of Rhode Island, provided information used to select cores that would be representative of the offshore sediments (King et al., this volume). Paleomagnetic profiles indicated more rapid accumulation of sediments at the more *northerly sites and hence a higher resolution for examining environmental change. Based on these observations, core 8 (site 3), core 4 (site 2), and core 3 (site 1) were selected as the primary records for detailed study.*

Cores 4 and 8 were selected for radiochemical analysis. Samples were obtained as 1-cm slices at GSC facilities in Dartmouth, and were prepared for several procedures at the Freshwater Institute (FWI), Department of Fisheries and Oceans, in Winnipeg. At the FWI the samples were freeze-dried and pulverized.

Radiochemical analyses were performed on the samples from cores 4 and 8, by Paul Wilkinson at the FWI. Lead-210 and Ra-226 were measured as described by Lockhart et al. (1998) by leaching the sediment with hydrochloric acid at 80°C. Polonium-210, the daughter of lead-210, was autoplated onto a silver disc from 1.5N HCl and the disc was counted with an alpha spectrometer (Flynn, 1968). Lead-210 was subsequently determined from Po-210 activity. The remaining acid solution was analyzed for Ra-226 by the Radon De-emanation Method (Mathieu, 1977). Cesium-137 and Ra-226 were counted on freeze-dried sediment using a gamma spectrometer (Wilkinson, 1985; Joshi, 1987).

RESULTS

Results for the radiochemical measurements are shown in Tables 1 and 2 for cores 4 and 8, respectively. The tables include the depth below the top of the core, dry weight, accumulated dry weight, porosity, thickness, and % water of the samples, as well as measured Pb-210, Cs-137 and Ra-226 activities and calculated excess Pb-210 values. Errors (+/- 1 standard deviation for Cs-137 and Ra-226, +/- 2 standard deviation for Pb-210) are also shown for the measured radiochemical activities. Excess Pb-210 was measurable to depths of 36 and 35 cm in cores 4 and 8, respectively.

Using the CRS method, the number of years per slice, as well as median ages and sedimentation rates for each slice, were calculated for the upper 35 and 34 cm of cores 4 and 8, respectively (Table 3). Median ages are given in the table, however, it should be pointed out that each 1-cm slice represents a range of possible ages from which analytical errors are calculated. Analytical errors for each age determination are also shown in the table, and were calculated by propagating analytical errors on Pb-210 activity and weights through the model calculations. Average sedimentation rates for the measured intervals were calculated using linear (Appleby and Oldfield, 1978; Robbins, 1978) and CRS sedimentation models (Table 4).

Exponential decays (R^2 = 0.93 for both) and sedimentation rate changes are indicated by changes in slope. CRS-derived average sedimentation rates for whole core profiles were 635 g/m^2/yr for core 4 and 861 g/m^2/yr for core 8. For core 8, there was a change in sedimentation rate at slice 13 (1970), from an average of 1070 g/m^2/yr to an average of 636 g/m^2/yr down to slice 25 (1909), where there was another change to 1250 g/m^2/yr for approximately a decade. Core 4 exhibits a change in average sedimentation rate from 957 g/m^2/yr to 581 g/m^2/yr at slice 6 (1987).

Also included in Table 4 are the measured and expected Pb-210 fluxes. Excess Pb-210 fluxes were calculated by multiplying the measured excess Pb-210 integral by the Pb-210 decay constant. The expected flux, or the estimate of atmopheric input, of Pb-210 was calculated from soil profiles taken at the Experimental Lakes Area (ELA) in northwestern Ontario and from the Red Lake, Ontario area. Since the Pb-210 flux is assumed constant for the CRS model, any excess Pb-210 flux is attributed to sediment focusing. The focus factor is a measure of the focusing of excess sediment at a site, and is determined by dividing measured excess Pb-210 flux by the expected flux. A focus factor greater than one indicates that a site is an area where reworked sediment has been deposited.

Downcore profiles of Pb-210 and Cs-137 for both cores are shown in Figure 2. The first detections of Cs-137 occur in 1915 and 1931 for cores 4 and 8, respectively (Table 1; Figure 2). Cesium-137 profiles rise to peak values in slices with Pb-210 ages of 1965 in core 4 and 1966 in core 8. For core 4, cesium values decline somewhat after peak values in the 1960's, but rise to a lesser peak dated at 1985 (6-7 cm). Above this, cesium values drop off slightly, before again rising towards the top of the profile, although never reaching values equivalent to peak values of the 1960's. Trends are similar for core 8, except that Cs-137 peaks were not as sharp and did not reach concentrations as great as those measured in core 4. The second Cs-137 peak in core 8 is dated at 1984 (7-8 cm). Also, a third Cs-137 peak was not detected in core 8.

DISCUSSION

Quality of Pb-210 profiles

Lead-210 dates are considered credible if they place peak Cs-137 activity in the mid 1960's, the period of peak fallout from the testing of nuclear bombs. The ages of peak Cs-137 activity for both cores did closely correspond with the mean age of maximum Cs-137 fallout, hence the Pb-210 age determinations are deemed to be of high quality.

The detection of low concentrations of Cs-137 significantly older than the date of peak nuclear bomb testing suggests that some vertical mixing of the sediments has occurred. However, mixing was not sufficient to obscure the Cs-137 peak that coincided with peak bomb fallout, suggesting that although Cs-137 mixing was deep, it was not laterally pervasive. Smearing of a small amount of sediment around the outer surface of the core, during coring operations, is a likely mechanism for the type of mixing observed (Joshi, 1989). Post-depositional mobility of Cs-137 is also a possible mechanism, although studies have shown that this effect is more likely in sediments having higher porosities and organic content than the cores examined in this study (Crusius and Anderson, 1995).

For both cores, the focus factor was less than one, indicating that the sites were not areas of sediment focusing. The sites received slightly less material than expected, based on comparisons with the estimated atmospheric input of Pb-210.

Sedimentation rates

Sedimentation rates for the measured interval, using the CRS method, were higher for core 8 (861 $g/m^2/yr$) than for core 4 (635 $g/m^2/yr$). Core 8, being the more southerly core, is more proximal to the input of the Red River. It is possible that the greater sedimentation rate at this site is the result of increased sediment input from the Red River, perhaps during floods. Alternatively, sediment resuspension by wind or wave may have altered the natural sedimentation rates, at least for the past 150 years.

Up-core shifts in the sedimentation rate, observed in both cores, could be attributed to processes that increase the rate of supply of sediments to the lake, such as varying climatic conditions or floods. Due to the shallow water depths in Lake Winnipeg, sediment resuspension through wind and wave action is also possible. The shift in sedimentation rate noted in the late 19^{th} century is perhaps due to anthropogenic changes to the landscape. Between the years 1881 and 1900 A.D., the population of southern Manitoba increased 4-fold (Statistics Canada, 1986) and the region became extensively used for agriculture. These changes may have caused increased runoff and erosion and, hence, higher rates of sediment supply to the lake.

Post 1960's Cs-137 source

Typically, Cs-137 values decrease steadily following peak values attributed to maximum bomb fallout. Increases in Cs-137 values in both cores after the 1960's indicate contribution of Cs-137 from an additional source. Increases in Cs-137 in the 1970's and 1980's has been observed in previous Lake Winnipeg cores (Lockhart et al., 2000), and has been attributed to leakage of this isotope from the Whiteshell Nuclear Research Establishment to the Winnipeg River (Lockhart et al, 2000; Lockhart et al., 2002). A spill from this establishment occurred in 1979 (Guthrie and Acres, 1980) and higher levels of Cs-137 were observed downstream from this establishment for several years afterwards (Winnipeg River Task Force, 1995).

A third increase in Cs-137 values at the top of core 4 only, corresponding to the 1990's, was not observed in core 8 or in other cores in the region. This increase could be the result of local metal remobilisation (e.g. Crusius and Anderson, 1995).

Integration of other chronological data

The post-1850 chronology for cores 4 and 8 is well constrained by Pb-210 and Cs-137. A *Salsola* marker (Anderson, this volume) tests and augments this chronology. Peak Cs-137 activity and the first sustained occurrence of *Salsola* pollen are within the error ranges assigned for Pb-210 dating, except for the first occurrence of *Salsola* in core 8, confirming that the ranges of estimated error are reasonable. In core 8, the first sustained occurrence of *Salsola* is at 1899 (1897-1902), which doesn't overlap with the estimated age of *Salsola* arrival to the lake in 1888-1893. However, the sampling interval at this depth was every 2 cm, so *Salsola* may have occurred in the underlying cm, which wasn't sampled for analysis. Lead-210 age estimates for these depths were 1892 and 1899 in cores 4 and 8, respectively.

The chronology for the upper portion of core 3 is limited to *Salsola* and a geochemical marker. Correlatable inter-core spikes in Ca, Mg and Cd occur throughout the cores and provide relative age markers (Table 5; Simpson and Thorleifson, this volume). For the top 15 cm of core 3, ages were estimated by averaging Pb-210 ages obtained from the tops of cores 4 and 8 (Table 6). Given that the *Salsola* marker occurs at similar depths in all three cores and that intact Pb-210, paleomagnetic and geochemical profiles indicate continuous sedimentation (King et al., this volume), it was assumed that the chronological profile for core 3 would be similar to that defined by Pb-210 dates in cores 4 and 8. Core 3 chronology between 15 and 27 cm was estimated by linear interpolation between a Cd marker at 15 cm, dated at 1936 (1932-1940) from an average of core 4 and core 8 ages, and the *Salsola* marker at 27 cm, dated at 1888 (Table 6).

Chronology for the lower portion of the cores was provided by interpolation between Pb-210 or *Salsola* and the paleomagnetic inclination marker I1 (Table 6; Figure 3). The age of I1 (King et al., this volume) was obtained from an AMS radiocarbon date of a composite insect sample at the depth of the I1 marker in core 9 (Telka, this volume). The radiocarbon age of 810 ± 35 yrs BP (CAMS-84850) was calibrated to provide a calendar age of AD 1230 +50/-70. The I1 marker occurred at a depth of 126, 132, and 120 cm in cores 3, 4 and 8, respectively. Preliminary ages for the inorganic geochemical markers were determined from linear interpolation between the lowest Pb-210 age or *Salsola* (core 3) and I1 in each core. The markers were then re-assigned ages based on an average of preliminary ages estimates for each core. Then ages between the lowest Pb-210 date or *Salsola* (core 3), the geochemical markers, and I1 were then determined by linear interpolation between these points.

Sedimentation rates shift from an average of 1.3-1.5 mm/yr in the pre-1900 period to an average of 2.6 mm/yr for the post-1900 portion of the cores. This shift is attributed either to post-depositional compaction or to an increase in sediment derived from enhanced runoff caused by landscape changes in the early 20th century, or possibly to a combination of the two. The pre-20th century sedimentation rate exceeds the previous sedimentation rate estimate of 1 mm/yr based on the 4000-yr record of south basin Lake Winnipeg sedimentation (Vance and Telka, 1998), implying that average sedimentation rates during the last 1000 years may have been slightly greater than the three preceding millennia.

CONCLUSIONS

- The occurrence of peak Cs-137 activity in the cores coincided with the period of peak fallout from nuclear bomb testing, indicating that Pb-210 age determinations are of high quality. The occurrence of Cs-137 in the cores below peak levels suggests that some smearing of sediments occurred during coring. Sediment focusing did not occur at these coring sites.

- Average sedimentation rates for the measured interval, using the CRS method, were higher for the more southern core (861 $g/m^2/yr$) than for the more northern core (635 $g/m^2/yr$).

- Shifts in sedimentation rates could be the result of climatic variations, floods, or sediment resuspension by wind or waves. Increases around the turn of the century could also be due to anthropogenic changes to the landscape.

- Increases in Cs-137 in the cores corresponding to the 1970's and 1980's is attributed to leakage from the Whiteshell Nuclear Research Establishment into the Winnipeg River.

- The post-1850 chronology is based on Pb-210, Cs-137, and a *Salsola* pollen marker.

- The pre-1850 chronology is based on linear interpolation between the lowest Pb-210 date and the paleomagnetic inclination marker I1.

- Sedimentation rates average 1.3-1.5 mm/yr pre 1900 and 2.6 mm/yr post 1900.

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Table 1. Radiochemical measurements for Lake Winnipeg 99-900 core 4

Depth (cm)	Dry Wt. (g)	Accumulated Dry Wt. (g/cm^2)	Porosity	Thickness (cm)	% Water (%)	Pb-210 Activity (Bq/g)	+/-	Error (Bq/g)	Cs-137 Activity (Bq/g)	+/-	Error (Bq/g)	Ra-226 Activity (Bq/g)	+/-	Error (Bq/g)	Excess Pb-210
0-1	8.3168	0.2133	0.55	0.71	75.0	1.49E-01	+/-	4.86E-03	7.42E-02	+/-	5.93E-03	4.00E-02	+/-	5.59E-03	1.09E-01
1-2	9.4424	0.4554	0.65	0.76	73.6	1.40E-01	+/-	4.70E-03	6.67E-02	+/-	4.67E-03	4.77E-02	+/-	3.81E-03	9.23E-02
2-3	7.6762	0.6522	0.61	0.64	74.4	1.46E-01	+/-	5.00E-03	6.64E-02	+/-	3.32E-03	5.09E-02	+/-	3.56E-03	9.51E-02
3-4	7.6665	0.8488	0.59	0.66	75.1	1.45E-01	+/-	3.67E-03	6.26E-02	+/-	5.01E-03	5.96E-02	+/-	7.16E-03	8.49E-02
4-5	5.8604	0.9990	0.49	0.51	75.4	1.45E-01	+/-	3.57E-03	5.53E-02	+/-	9.39E-03	5.57E-02	+/-	8.91E-03	8.90E-02
5-6	7.0268	1.1792	0.68	0.62	75.7	1.54E-01	+/-	3.98E-03	6.67E-02	+/-	4.00E-03	4.89E-02	+/-	2.44E-03	1.05E-01
6-7	6.6924	1.3508	0.60	0.59	75.5	1.53E-01	+/-	3.77E-03	6.72E-02	+/-	7.39E-03	4.96E-02	+/-	5.95E-03	1.04E-01
7-8	7.6116	1.5460	0.64	0.67	75.4	1.53E-01	+/-	4.40E-03	4.73E-02	+/-	5.68E-03	4.28E-02	+/-	5.56E-03	1.10E-01
8-9	8.1778	1.7557	0.60	0.70	74.9	1.40E-01	+/-	4.10E-03	6.24E-02	+/-	4.37E-03	5.35E-02	+/-	3.74E-03	8.67E-02
9-10	6.8059	1.9302	0.58	0.57	74.5	1.36E-01	+/-	3.99E-03	7.78E-02	+/-	7.00E-03	4.72E-02	+/-	6.14E-03	8.90E-02
10-11	7.5840	2.1246	0.62	0.63	74.3	1.36E-01	+/-	4.20E-03	7.85E-02	+/-	6.28E-03	4.73E-02	+/-	5.21E-03	8.83E-02
11-12	7.3659	2.3135	0.51	0.60	74.0	1.30E-01	+/-	3.92E-03	8.22E-02	+/-	4.11E-03	5.94E-02	+/-	4.75E-03	7.08E-02
12-13	8.3713	2.5281	0.64	0.67	73.7	1.22E-01	+/-	3.65E-03	9.00E-02	+/-	6.30E-03	5.37E-02	+/-	5.90E-03	6.87E-02
13-14	10.0636	2.7862	0.64	0.77	72.6	1.09E-01	+/-	3.34E-03	7.11E-02	+/-	4.26E-03	4.33E-02	+/-	4.76E-03	6.57E-02
14-15	8.6741	3.0086	0.57	0.66	72.3	9.84E-02	+/-	3.54E-03	4.92E-02	+/-	3.44E-03	4.23E-02	+/-	3.81E-03	5.61E-02
15-16	9.6273	3.2555	0.59	0.73	72.2	9.54E-02	+/-	2.96E-03	4.77E-02	+/-	2.86E-03	3.48E-02	+/-	3.13E-03	6.07E-02
16-17	8.7802	3.4806	0.59	0.68	72.7	8.14E-02	+/-	3.17E-03	2.59E-02	+/-	1.55E-03	4.37E-02	+/-	2.19E-03	3.77E-02
17-18	9.4131	3.7220	0.65	0.72	72.5	7.68E-02	+/-	2.39E-03	2.51E-02	+/-	2.26E-03	4.22E-02	+/-	2.95E-03	3.46E-02
18-19	9.2066	3.9580	0.60	0.69	71.9	7.17E-02	+/-	2.30E-03	2.08E-02	+/-	2.29E-03	4.09E-02	+/-	3.27E-03	3.08E-02
19-20	8.0290	4.1639	0.56	0.61	72.3	6.97E-02	+/-	2.07E-03	1.31E-02	+/-	1.84E-03	4.43E-02	+/-	2.66E-03	2.54E-02
20-21	9.5372	4.4084	0.60	0.72	72.3	6.88E-02	+/-	1.99E-03	1.16E-02	+/-	1.97E-03	4.58E-02	+/-	3.21E-03	2.29E-02
21-22	9.5274	4.6527	0.61	0.71	71.9	6.29E-02	+/-	2.09E-03	3.16E-03	+/-	1.93E-03	4.08E-02	+/-	3.27E-03	2.20E-02
22-23	10.7430	4.9282	0.63	0.79	71.6	6.02E-02	+/-	1.66E-03	0.00E+00	+/-	0.00E+00	4.97E-02	+/-	2.98E-03	1.05E-02
23-24	9.2084	5.1643	0.57	0.68	71.6	5.76E-02	+/-	1.64E-03							1.19E-02
24-25	10.4127	5.4313	0.66	0.77	71.7	5.61E-02	+/-	1.66E-03							1.04E-02
25-26	10.7675	5.7074	0.60	0.79	71.4	5.60E-02	+/-	1.69E-03							1.03E-02
26-27	10.1063	5.9665	0.60	0.75	71.8	5.47E-02	+/-	1.73E-03							9.04E-03
27-28	10.4144	6.2336	0.69	0.75	71.2	4.92E-02	+/-	1.77E-03							3.55E-03
28-29	10.3318	6.4985	0.66	0.74	71.1	4.91E-02	+/-	1.57E-03							3.44E-03

Table 1 continued

Depth (cm)	Dry Wt. (g)	Accumulated Dry Wt. (g/cm^2)	Porosity	Thickness (cm)	% Water (%)	Pb-210 Activity (Bq/g)	+/-	Error (Bq/g)	Cs-137 Activity (Bq/g)	+/-	Error (Bq/g)	Ra-226 Activity (Bq/g)	+/-	Error (Bq/g)	Excess Pb-210
29-30	10.0826	6.7570	0.63	0.72	70.9	4.90E-02	+/-	1.68E-03							3.35E-03
30-31	10.7082	7.0316	0.60	0.75	70.6	4.73E-02	+/-	2.14E-03							1.62E-03
31-32	9.9536	7.2868	0.65	0.70	70.6	5.10E-02	+/-	1.83E-03							5.32E-03
32-33	10.2929	7.5507	0.62	0.73	70.9	5.17E-02	+/-	1.88E-03							5.95E-03
33-34	10.7211	7.8256	0.65	0.75	70.4	4.80E-02	+/-	1.60E-03							2.30E-03
34-35	11.8599	8.1297	0.63	0.81	69.8	4.83E-02	+/-	1.60E-03							2.60E-03
35-36	10.5323	8.3998	0.65	0.72	70.0	4.75E-02	+/-	1.54E-03							1.81E-03
36-37	11.3337	8.6904	0.57	0.78	70.0	4.50E-02	+/-	1.54E-03							
37-38	12.3795	9.0078	0.65	0.86	70.2	4.57E-02	+/-	1.37E-03							
38-39	12.0320	9.3163	0.59	0.84	70.5	4.57E-02	+/-	1.46E-03							
39-40	10.0598	9.5743	0.61	0.69	70.1	4.60E-02	+/-	1.37E-03							
40-41	12.9654	9.9067	0.67	0.88	69.8	4.54E-02	+/-	2.15E-03							
41-42	10.0730	10.1650	0.62	0.68	69.7	4.62E-02	+/-	1.37E-03							
42-43	11.5264	10.4605	0.61	0.78	69.7	4.64E-02	+/-	2.30E-03							
43-44	10.8701	10.7393	0.53	0.72	69.2	4.50E-02	+/-	1.28E-03							
44-45	11.5329	11.0350	0.64	0.78	69.6	4.57E-02	+/-	1.19E-03							
45-46	11.8180	11.3380	0.58	0.79	69.2	4.58E-02	+/-	1.20E-03							
46-47	11.4253	11.6310	0.58	0.76	69.3										
47-48	12.6383	11.9550	0.61	0.83	69.0										
48-49	11.7755	12.2569	0.64	0.78	69.0										
49-50	10.9910	12.5388	0.52	0.77	70.5										
50-51	9.5115	12.7827	0.58	0.66	70.2										
51-52	10.6121	13.0548	0.61	0.73	70.1										
52-53	11.4702	13.3489	0.61	0.78	69.8										
53-54	11.9309	13.6548	0.59	0.81	69.6										
54-55	11.6022	13.9523	0.60	0.79	69.9										
55-56	11.5880	14.2494	0.59	0.78	69.5										
56-57	12.5892	14.5722	0.62	0.84	69.3										
57-58	11.9633	14.8790	0.65	0.84	70.5										
58-59	10.7299	15.1541	0.64	0.75	70.5										

Table 1 continued

Depth (cm)	Dry Wt. (g)	Accumulated Dry Wt. (g/cm^2)	Porosity	Thickness (cm)	% Water (%)	Pb-210 Activity (Bq/g)	+/- Error (Bq/g)	Cs-137 Activity (Bq/g)	+/- Error (Bq/g)	Ra-226 Activity (Bq/g)	+/- Error (Bq/g)	Excess Pb-210
59-60	11.2213	15.4418	0.65	0.77	70.1							
60-61	10.8470	15.7199	0.60	0.75	70.1							
61-62	12.5588	16.0420	0.60	0.84	69.5							
62-63	12.0335	16.3505	0.62	0.81	69.6							
63-64	12.2362	16.6643	0.63	0.81	69.1							
64-65	10.8207	16.9417	0.62	0.74	69.8							
65-66	12.3160	17.2575	0.61	0.83	69.6							
66-67	11.3545	17.5486	0.62	0.76	69.5							
67-68	12.5052	17.8693	0.64	0.83	69.2							
68-69	11.1236	18.1545	0.53	0.74	69.1							
69-70	10.5436	18.4249	0.54	0.68	68.6							
70-71	12.8875	18.7553	0.57	0.84	68.8							
71-72	13.5676	19.1032	0.63	0.87	68.3							
72-73	12.3825	19.4207	0.59	0.77	67.5							
73-74	13.0015	19.7541	0.58	0.80	67.4							
74-75	13.0136	20.0878	0.57	0.80	67.3							
75-76	12.1466	20.3992	0.55	0.76	67.5							
76-77	13.7028	20.7506	0.57	0.86	67.6							
77-78	12.6805	21.0757	0.62	0.78	67.4							
78-79	12.6961	21.4012	0.62	0.79	67.7							
79-80	12.4016	21.7192	0.57	0.78	67.8							
80-81	11.9954	22.0268	0.58	0.75	67.8							
81-82	12.6843	22.3520	0.57	0.82	68.4							
82-83	13.1784	22.6899	0.65	0.83	67.9							
83-84	12.8014	23.0182	0.59	0.76	66.3							
84-85	12.7438	23.3450	0.55	0.75	66.2							
85-86	14.1826	23.7086	0.60	0.84	66.4							
86-87	13.1672	24.0462	0.55	0.79	66.7							
87-88	12.9940	24.3794	0.56	0.80	67.4							
88-89	12.9417	24.7112	0.52	0.81	67.5							

Table 1 continued

Depth (cm)	Dry Wt. (g)	Accumulated Dry Wt. (g/cm^2)	Porosity	Thickness (cm)	% Water (%)	Pb-210 Activity (Bq/g)	+/- Error (Bq/g)	Cs-137 Activity (Bq/g)	+/- Error (Bq/g)	Ra-226 Activity (Bq/g)	+/- Error (Bq/g)	Excess Pb-210
89-90	14.7316	25.0890	0.57	0.88	66.6							
90-91	12.3334	25.4052	0.54	0.77	67.5							
91-92	12.9889	25.7383	0.57	0.79	67.0							
92-93	13.4179	26.0823	0.58	0.79	66.2							
93-94	14.8117	26.4621	0.56	0.84	65.1							
94-95	12.9392	26.7939	0.57	0.76	65.9							
95-96	12.8475	27.1233	0.52	0.78	66.8							
96-97	16.7211	27.5521	0.57	0.99	66.2							
97-98	14.7052	27.9291	0.58	0.86	66.0							
98-99	13.8745	28.2849	0.55	0.82	66.3							
99-100	14.3937	28.6539	0.55	0.86	66.5							
100-101	11.9837	28.9612	0.46	0.73	67.1							
101-102	13.6935	29.3123	0.50	0.81	66.3							
102-103	12.5406	29.6339	0.54	0.72	65.5							
103-104	14.5297	30.0064	0.50	0.83	65.2							
104-105	13.5746	30.3545	0.55	0.78	65.6							
105-106	13.5877	30.7029	0.57	0.83	67.2							
106-107	12.8742	31.0330	0.53	0.79	67.1							
107-108	13.5206	31.3797	0.59	0.82	66.9							
108-109	12.8899	31.7102	0.58	0.78	66.9							
109-110	12.4674	32.0299	0.52	0.75	66.5							
110-111	12.7546	32.3569	0.48	0.76	66.6							
111-112	13.5609	32.7046	0.55	0.80	66.3							
112-113	14.9155	33.0871	0.56	0.91	67.0							
113-114	12.3976	33.4050	0.51	0.74	66.6							
114-115	15.8528	33.8115	0.59	0.91	65.5							
115-116	12.9044	34.1423	0.50	0.72	64.6							
116-117	12.8598	34.4721	0.54	0.72	64.7							
117-118	16.2120	34.8878	0.49	0.89	64.3							
118-119	12.9740	35.2204	0.53	0.72	64.6							

Table 1 continued

Depth (cm)	Dry Wt. (g)	Accumulated Dry Wt. (g/cm^2)	Porosity	Thickness (cm)	% Water (%)	Pb-210 Activity (Bq/g)	+/- Error (Bq/g)	Cs-137 Activity (Bq/g)	+/- Error (Bq/g)	Ra-226 Activity (Bq/g)	+/- Error (Bq/g)	Excess Pb-210
119-120	15.0014	35.6051	0.54	0.85	65.1							
120-121	12.9195	35.9364	0.54	0.74	65.6							
121-122	15.3719	36.3305	0.59	0.89	65.7							
122-123	16.9648	36.7655	0.64	0.99	65.8							
123-124	18.6920	37.2448	0.62	1.09	66.0							
124-125	18.1574	37.7104	0.65	1.05	65.6							
125-126	16.5411	38.1345	0.61	0.96	65.7							
126-127	16.9407	38.5689	0.62	0.99	66.0							
127-128	19.2682	39.0629	0.64	1.10	65.3							
128-129	18.5363	39.5382	0.61	1.03	64.5							
129-130	16.2215	39.9542	0.56	0.91	64.7							
130-131	16.7458	40.3835	0.62	0.92	64.3							
131-132	18.1144	40.8480	0.57	1.02	65.1							
132-133	16.3945	41.2684	0.57	0.93	65.0							
133-134	17.0571	41.7057	0.54	0.95	64.7							
134-135	19.4648	42.2048	0.59	1.09	64.8							
135-136	17.1645	42.6450	0.59	1.00	65.7							
136-137	15.9450	43.0538	0.57	0.93	65.9							
137-138	19.6300	43.5571	0.59	1.12	65.3							
138-139	16.0128	43.9677	0.65	0.91	65.0							
139-140	19.3248	44.4632	0.58	1.09	65.1							
140-141	16.7466	44.8926	0.59	0.93	64.6							
141-142	19.6041	45.3953	0.60	1.06	63.8							
142-143	20.9100	45.9314	0.63	1.13	63.9							
143-144	16.8941	46.3646	0.58	0.93	64.3							
144-145	22.1343	46.9322	0.61	1.21	64.2							
145-146	17.2362	47.3741	0.59	0.93	63.8							
146-147	20.1848	47.8917	0.63	1.08	63.7							
147-148	18.9125	48.3766	0.64	1.02	63.9							
148-149	19.2208	48.8695	0.56	1.04	63.8							

Table 1 continued

Depth (cm)	Dry Wt. (g)	Accumulated Dry Wt. (g/cm^2)	Porosity	Thickness (cm)	% Water (%)	Pb-210 Activity (Bq/g)	+/- Error (Bq/g)	Cs-137 Activity (Bq/g)	+/- Error (Bq/g)	Ra-226 Activity (Bq/g)	+/- Error (Bq/g)	Excess Pb-210
149-150	18.8434	49.3526	0.54	1.01	63.6							
150-151	19.6180	49.8557	0.58	1.06	63.8							
151-152	15.4733	50.2524	0.53	0.83	63.7							
152-153	20.3787	50.7749	0.60	1.09	63.4							
153-154	20.6753	51.3051	0.60	1.11	63.6							
154-155	20.7815	51.8379	0.60	1.12	63.7							
155-156	19.8033	52.3457	0.62	1.04	63.0							
156-157	16.4259	52.7669	0.52	0.88	63.7							
157-158	19.6825	53.2716	0.60	1.04	63.2							
158-159	20.1644	53.7886	0.59	1.07	63.4							
159-160	20.6304	54.3176	0.56	1.08	63.0							
160-161	22.0617	54.8833	0.57	1.09	61.2							
161-162	24.0826	55.5008	0.58	1.09	58.6							

Table 2. Radiochemical measurements for Lake Winnipeg 99-900 core 8

Depth (cm)	Dry Wt. (g)	Accumulated Dry Wt. (g/cm^2)	Porosity	Thickness (cm)	% Water (%)	Pb-210 Activity (Bq/g)	+/-	Error (Bq/g)	Cs-137 Activity (Bq/g)	+/-	Error (Bq/g)	Ra-226 Activity (Bq/g)	+/-	Error (Bq/g)	Excess Pb-210
0-1	10.9335	0.2803	0.61	0.84	72.5	1.39E-01	+/-	5.65E-03							8.91E-02
1-2	10.8619	0.5589	0.65	0.83	72.6	1.38E-01	+/-	5.18E-03							8.79E-02
2-3	9.1953	0.7946	0.65	0.71	72.6	1.40E-01	+/-	6.56E-03							8.97E-02
3-4	8.4185	1.0105	0.64	0.66	73.0	1.43E-01	+/-	5.64E-03							9.31E-02
4-5	9.2753	1.2483	0.70	0.73	73.2	1.30E-01	+/-	4.69E-03							8.00E-02
5-6	6.7199	1.4206	0.63	0.53	73.3	1.33E-01	+/-	5.04E-03	4.21E-02	+/-	3.79E-03				8.27E-02
6-7	8.8638	1.6479	0.66	0.70	73.1	1.31E-01	+/-	5.14E-03	4.87E-02	+/-	2.43E-03				8.06E-02
7-8	9.0737	1.8806	0.64	0.71	73.1	1.27E-01	+/-	5.20E-03	5.06E-02	+/-	2.53E-03				7.68E-02
8-9	11.4181	2.1733	0.68	0.89	72.8	1.22E-01	+/-	5.30E-03	4.81E-02	+/-	9.61E-04				7.24E-02
9-10	10.5859	2.4448	0.68	0.82	72.8	1.24E-01	+/-	5.31E-03	4.32E-02	+/-	2.16E-03	4.79E-02	+/-	3.61E-03	7.44E-02
10-11	7.9153	2.6477	0.64	0.62	73.2	1.15E-01	+/-	5.87E-03	5.33E-02	+/-	1.07E-03	5.44E-02	+/-	1.63E-03	6.52E-02
11-12	7.9464	2.8515	0.67	0.63	73.3	1.17E-01	+/-	3.57E-03	5.16E-02	+/-	2.58E-03	5.50E-02	+/-	3.30E-03	6.70E-02
12-13	11.4542	3.1452	0.70	0.89	72.9	1.16E-01	+/-	5.57E-03	5.01E-02	+/-	2.00E-03	4.63E-02	+/-	2.78E-03	6.64E-02
13-14	10.2662	3.4084	0.70	0.77	72.2	1.17E-01	+/-	3.61E-03	5.39E-02	+/-	2.16E-03	4.42E-02	+/-	2.65E-03	6.69E-02
14-15	11.1703	3.6948	0.65	0.84	72.1	1.11E-01	+/-	5.25E-03	5.15E-02	+/-	1.55E-03	4.77E-02	+/-	1.91E-03	6.12E-02
15-16	11.1561	3.9809	0.71	0.82	71.5	1.05E-01	+/-	5.16E-03	4.56E-02	+/-	1.37E-03	4.46E-02	+/-	1.79E-03	5.50E-02
16-17	12.3118	4.2966	0.67	0.90	71.4	1.01E-01	+/-	3.39E-03	3.93E-02	+/-	1.97E-03	4.60E-02	+/-	2.76E-03	5.11E-02
17-18	12.1028	4.6069	0.64	0.86	70.9	9.13E-02	+/-	2.78E-03	2.71E-02	+/-	1.62E-03	5.14E-02	+/-	2.57E-03	4.13E-02
18-19	13.5935	4.9554	0.70	0.94	70.1	8.20E-02	+/-	3.15E-03	2.12E-02	+/-	1.48E-03	4.59E-02	+/-	2.30E-03	3.20E-02
19-20	13.5178	5.3021	0.64	0.92	69.8	7.66E-02	+/-	2.79E-03	1.57E-02	+/-	9.42E-04	5.38E-02	+/-	2.69E-03	2.66E-02
20-21	12.1107	5.6126	0.69	0.81	69.5	7.06E-02	+/-	2.35E-03							2.06E-02
21-22	14.2017	5.9767	0.68	0.95	69.4	6.77E-02	+/-	2.61E-03							1.77E-02
22-23	13.3804	6.3198	0.69	0.91	69.7	6.49E-02	+/-	2.71E-03							1.49E-02
23-24	17.1122	6.7586	0.72	1.15	69.4	6.00E-02	+/-	2.67E-03							1.00E-02
24-25	12.2393	7.0724	0.68	0.81	69.0	5.68E-02	+/-	2.43E-03							6.81E-03
25-26	17.1679	7.5126	0.71	1.13	69.0	5.65E-02	+/-	2.42E-03							6.49E-03
26-27	12.8146	7.8412	0.71	0.86	69.6	5.39E-02	+/-	2.63E-03							3.87E-03
27-28	13.5789	8.1894	0.72	0.92	69.7	5.43E-02	+/-	2.37E-03							4.28E-03
28-29	12.7583	8.5165	0.69	0.84	69.1	5.60E-02	+/-	2.46E-03							6.00E-03

Table 2 continued

Depth (cm)	Dry Wt. (g)	Accumulated Dry Wt. (g/cm^2)	Porosity	Thickness (cm)	% Water (%)	Pb-210 Activity (Bq/g)	+/-	Error (Bq/g)	Cs-137 Activity (Bq/g)	+/-	Error (Bq/g)	Ra-226 Activity (Bq/g)	+/-	Error (Bq/g)	Excess Pb-210
29-30	14.8398	8.8970	0.64	0.98	69.0	5.57E-02	+/-	2.61E-03							5.69E-03
30-31	14.7066	9.2741	0.68	0.95	68.4	5.64E-02	+/-	2.86E-03							6.38E-03
31-32	15.6650	9.6758	0.70	1.03	68.8	5.49E-02	+/-	2.55E-03							4.91E-03
32-33	13.8093	10.0299	0.72	0.89	68.6	5.47E-02	+/-	2.37E-03							4.74E-03
33-34	16.0559	10.4416	0.71	1.03	68.4	5.46E-02	+/-	1.99E-03							4.55E-03
34-35	13.8848	10.7976	0.67	0.88	68.0	5.33E-02	+/-	1.98E-03							3.32E-03
35-36	14.3328	11.1651	0.62	0.91	68.1	5.13E-02	+/-	1.93E-03							
36-37	16.3131	11.5834	0.71	1.02	67.8	5.25E-02	+/-	2.01E-03							
37-38	16.1894	11.9985	0.66	1.04	68.3	4.85E-02	+/-	1.84E-03							
38-39	14.0812	12.3595	0.67	0.91	68.5	4.97E-02	+/-	2.46E-03							
39-40	15.4215	12.7550	0.68	0.98	68.0	4.97E-02	+/-	2.31E-03							
40-41	16.4328	13.1763	0.64	1.01	67.3										
41-42	14.1894	13.5402	0.67	0.89	67.6										
42-43	17.0000	13.9760	0.67	1.05	67.4										
43-44	14.7082	14.3532	0.60	0.90	67.0										
44-45	14.7351	14.7310	0.61	0.90	67.2										
45-46	16.4658	15.1532	0.69	1.04	67.9										
46-47	12.7527	15.4802	0.65	0.79	67.5										
47-48	15.8909	15.8877	0.68	0.98	67.2										
48-49	14.9259	16.2704	0.63	0.92	67.2										
49-50	18.3245	16.7402	0.67	1.12	67.0										
50-51	14.5630	17.1136	0.61	0.87	66.6										
51-52	17.4612	17.5614	0.62	1.04	66.4										
52-53	16.4299	17.9826	0.65	0.99	66.8										
53-54	15.1495	18.3711	0.68	0.92	67.0										
54-55	17.7956	18.8274	0.67	1.08	66.9										
55-56	14.1912	19.1913	0.63	0.88	67.3										
56-57	16.5480	19.6156	0.69	1.02	67.2										
57-58	15.0799	20.0022	0.63	0.94	67.5										
58-59	13.7675	20.3553	0.62	0.88	68.2										

Table 2 continued

Depth (cm)	Dry Wt. (g)	Accumulated Dry Wt. (g/cm^2)	Porosity	Thickness (cm)	% Water (%)	Pb-210 Activity (Bq/g)	+/- Error (Bq/g)	Cs-137 Activity (Bq/g)	+/- Error (Bq/g)	Ra-226 Activity (Bq/g)	+/- Error (Bq/g)	Excess Pb-210
59-60	17.3883	20.8011	0.66	1.10	68.1							
60-61	11.7684	21.1029	0.57	0.75	68.1							
61-62	18.9470	21.5887	0.67	1.17	67.4							
62-63	16.5116	22.0121	0.66	1.02	67.3							
63-64	14.9607	22.3957	0.65	0.95	68.2							
64-65	15.0633	22.7819	0.68	0.96	68.1							
65-66	15.1578	23.1706	0.62	0.96	68.0							
66-67	14.3867	23.5395	0.64	0.90	67.8							
67-68	15.9160	23.9476	0.59	0.97	67.0							
68-69	16.2287	24.3637	0.69	0.95	65.9							
69-70	18.3794	24.8349	0.64	1.07	65.7							
70-71	15.9494	25.2439	0.64	0.93	66.0							
71-72	14.8665	25.6251	0.57	0.87	66.0							
72-73	17.2351	26.0670	0.58	1.01	66.1							
73-74	14.1922	26.4309	0.63	0.82	65.7							
74-75	17.0883	26.8691	0.63	1.00	66.0							
75-76	17.7543	27.3243	0.60	1.04	65.9							
76-77	13.6637	27.6747	0.63	0.79	65.6							
77-78	16.5482	28.0990	0.66	0.96	65.6							
78-79	18.7961	28.5809	0.61	1.06	64.9							
79-80	15.5927	28.9808	0.60	0.91	65.9							
80-81	19.1875	29.4727	0.61	1.09	65.2							
81-82	15.4928	29.8700	0.67	0.90	65.8							
82-83	18.0314	30.3323	0.60	1.02	65.2							
83-84	17.1392	30.7718	0.61	1.00	66.0							
84-85	17.5408	31.2216	0.62	1.04	66.2							
85-86	12.6398	31.5457	0.57	0.75	66.4							
86-87	18.7337	32.0260	0.68	1.10	66.1							
87-88	17.4002	32.4722	0.67	1.02	66.1							
88-89	15.9517	32.8812	0.65	0.93	65.7							

Table 2 continued

Depth (cm)	Dry Wt. (g)	Accumulated Dry Wt. (g/cm^2)	Porosity	Thickness (cm)	% Water (%)	Pb-210 Activity (Bq/g)	+/- Error (Bq/g)	Cs-137 Activity (Bq/g)	+/- Error (Bq/g)	Ra-226 Activity (Bq/g)	+/- Error (Bq/g)	Excess Pb-210
89-90	15.6203	33.2817	0.65	0.90	65.5							
90-91	15.4393	33.6776	0.62	0.85	64.2							
91-92	17.0970	34.1160	0.65	0.97	65.3							
92-93	17.1802	34.5565	0.63	0.98	65.4							
93-94	17.5960	35.0077	0.62	1.00	65.1							
94-95	16.5915	35.4331	0.62	0.94	65.1							
95-96	20.7597	35.9654	0.61	1.16	64.8							
96-97	13.6432	36.3152	0.57	0.75	64.1							
97-98	16.5284	36.7390	0.58	0.91	64.4							
98-99	19.1192	37.2293	0.59	0.97	62.0							
99-100	19.7736	37.7363	0.58	1.06	63.6							
100-101	15.7651	38.1405	0.62	0.92	66.0							
101-102	17.5923	38.5916	0.62	0.99	64.9							
102-103	19.3113	39.0868	0.62	1.06	64.2							
103-104	15.1154	39.4743	0.58	0.82	63.9							
104-105	18.4568	39.9476	0.61	1.08	65.9							
105-106	18.6407	40.4256	0.66	1.07	65.6							
106-107	17.8492	40.8832	0.60	0.99	64.4							
107-108	17.2012	41.3243	0.57	0.91	63.4							
108-109	16.6292	41.7507	0.53	0.89	63.5							
109-110	18.4908	42.2248	0.60	1.02	64.5							
110-111	15.6148	42.6252	0.57	0.85	63.8							
111-112	15.4714	43.0219	0.60	0.86	64.5							
112-113	15.3248	43.4148	0.51	0.84	64.1							
113-114	16.2126	43.8305	0.59	0.92	65.2							
114-115	16.4456	44.2522	0.56	0.91	64.6							
115-116	16.4295	44.6735	0.55	0.91	64.4							
116-117	18.6350	45.1513	0.52	0.99	63.4							
117-118	14.6922	45.5280	0.52	0.75	62.3							
118-119	27.0825	46.2225	0.65	1.37	61.9							

Table 2 continued

Depth (cm)	Dry Wt. (g)	Accumulated Dry Wt. (g/cm^2)	Porosity	Thickness (cm)	% Water (%)	Pb-210 Activity (Bq/g)	+/- Error (Bq/g)	Cs-137 Activity (Bq/g)	+/- Error (Bq/g)	Ra-226 Activity (Bq/g)	+/- Error (Bq/g)	Excess Pb-210
119-120	14.0731	46.5833	0.49	0.70	61.5							
120-121	18.4204	47.0556	0.54	0.91	61.2							
121-122	17.4733	47.5037	0.58	0.87	61.4							
122-123	18.0032	47.9653	0.55	0.89	61.4							
123-124	18.1501	48.4307	0.55	0.90	61.3							
124-125	15.8908	48.8381	0.49	0.79	61.5							
125-126	19.6964	49.3431	0.59	0.97	61.3							
126-127	17.1997	49.7842	0.53	0.85	61.3							
127-128	18.6928	50.2635	0.59	0.92	61.3							
128-129	16.5537	50.6879	0.55	0.83	61.8							
129-130	16.7850	51.1183	0.60	0.84	61.8							
130-131	14.3283	51.4857	0.52	0.71	61.5							
131-132	18.1049	51.9499	0.54	0.89	61.1							
132-133	16.8560	52.3821	0.57	0.84	61.6							
133-134	20.0402	52.8960	0.60	1.00	61.5							
134-135	19.5736	53.3979	0.56	0.95	60.8							
135-136	18.7820	53.8795	0.55	0.94	61.7							
136-137	15.4740	54.2762	0.56	0.80	62.5							
137-138	17.5963	54.7274	0.58	0.88	61.6							
138-139	16.4322	55.1488	0.55	0.85	62.5							
139-140	17.1852	55.5894	0.58	0.88	62.2							
140-141	17.7665	56.0450	0.62	0.90	62.0							
141-142	19.0914	56.5345	0.57	0.96	61.7							
142-143	18.6477	57.0126	0.62	0.92	61.2							
143-144	17.1337	57.4519	0.52	0.85	61.5							
144-145	17.7040	57.9059	0.62	0.89	61.8							
145-146	17.2791	58.3489	0.51	0.89	62.4							
146-147	18.3370	58.8191	0.58	0.91	61.5							
147-148	18.5952	59.2959	0.57	0.93	61.7							
148-149	19.4696	59.7951	0.63	0.99	62.0							

Table 2 continued

Depth (cm)	Dry Wt. (g)	Accumulated Dry Wt. (g/cm^2)	Porosity	Thickness (cm)	% Water (%)	Pb-210 Activity (Bq/g) +/- Error (Bq/g)	Cs-137 Activity (Bq/g) +/- Error (Bq/g)	Ra-226 Activity (Bq/g) +/- Error (Bq/g)	Excess Pb-210
149-150	19.2590	60.2890	0.61	0.92	60.1				
150-151	17.7974	60.7453	0.58	0.87	60.8				
151-152	18.4332	61.2180	0.57	0.91	61.2				
152-153	16.7525	61.6475	0.59	0.84	61.9				
153-154	18.8825	62.1317	0.56	0.95	61.7				
154-155	18.7928	62.6135	0.61	0.95	62.1				
155-156	18.0601	63.0766	0.64	0.91	61.7				
156-157	14.6292	63.4517	0.55	0.72	61.1				
157-158	14.3048	63.8185	0.53	0.70	61.0				

Table 3. Pb-210 age determinations and sedimentation rates for Lake Winnipeg 99-900 cores 4 and 8, based on the Constant Rate of Supply (CRS) model.

Core 4									
Depth (cm)	#Years/slice (years)	+/- error on #years/slice	Median yr (years AD)	Age range of slice -	Age range of slice +	Age range with error -	Age range with error +	Sed Rate ($g/m^2/yr$)	+/- error on sed rate
0-1	2.3	0.8	1998	1997	1999	1996	2000	942	342
1-2	2.3	0.9	1996	1994	1997	1993	1998	1034	423
2-3	2.1	0.5	1993	1992	1994	1991	1996	937	223
3-4	2.0	0.4	1991	1990	1992	1989	1993	984	180
4-5	1.7	0.2	1989	1989	1990	1988	1991	887	138
5-6	2.6	0.3	1987	1986	1989	1985	1990	704	97
6-7	2.6	0.3	1985	1983	1986	1982	1987	657	81
7-8	3.5	0.4	1982	1980	1983	1979	1985	561	63
8-9	3.3	0.3	1978	1977	1980	1976	1981	643	68
9-10	3.1	0.3	1975	1974	1977	1973	1978	568	58
10-11	3.8	0.3	1972	1970	1974	1969	1975	515	51
11-12	3.3	0.3	1968	1967	1970	1965	1971	575	57
12-13	4.1	0.3	1965	1963	1967	1961	1968	529	52
13-14	5.4	0.5	1960	1957	1963	1956	1964	478	48
14-15	4.7	0.4	1955	1952	1957	1951	1958	478	50
15-16	6.7	0.6	1949	1946	1952	1945	1954	371	41
16-17	4.5	0.5	1944	1941	1946	1940	1947	501	58
17-18	5.1	0.6	1939	1936	1941	1935	1942	470	58
18-19	5.2	0.6	1934	1931	1936	1930	1937	450	59
19-20	4.4	0.6	1929	1927	1931	1925	1932	469	66
20-21	5.5	0.8	1924	1921	1927	1920	1928	446	68
21-22	6.3	1.0	1918	1915	1921	1913	1922	387	65
22-23	4.0	0.7	1913	1911	1915	1910	1916	692	128
23-24	4.4	0.9	1909	1906	1911	1905	1912	534	107
24-25	5.1	1.1	1904	1901	1906	1900	1908	526	116
25-26	6.2	1.5	1898	1895	1901	1893	1903	447	111
26-27	6.2	1.7	1892	1889	1895	1887	1897	420	119
27-28	2.9	0.9	1887	1886	1889	1885	1890	929	289
28-29	3.0	1.0	1885	1883	1886	1882	1887	874	290
29-30	3.2	1.1	1881	1880	1883	1878	1885	816	291
30-31	1.8	0.7	1879	1878	1880	1877	1881	1564	591
31-32	6.1	2.5	1875	1872	1878	1869	1881	422	175
32-33	8.8	4.4	1868	1863	1872	1859	1877	299	149
33-34	4.4	2.5	1861	1859	1863	1856	1866	630	364
34-35	6.5	4.3	1856	1852	1859	1848	1863	471	312

Table 3 continued

Core 8									
Depth (cm)	#Years/slice (years)	+/- error on #years/slice	Median yr (years AD)	Age range of slice		Age range with error		Sed Rate ($g/m^2/yr$)	+/- error on sed rate
				-	+	-	+		
0-1	2.1	1.0	1998	1997	1999	1996	2000	1354	689
1-2	2.2	1.2	1996	1995	1997	1993	1999	1284	734
2-3	2.0	0.6	1994	1993	1995	1992	1996	1180	383
3-4	2.0	0.5	1992	1991	1993	1990	1994	1067	259
4-5	2.0	0.4	1990	1989	1991	1988	1992	1167	233
5-6	1.6	0.3	1988	1987	1989	1986	1990	1066	187
6-7	2.2	0.3	1986	1985	1987	1984	1988	1030	164
7-8	2.3	0.3	1984	1983	1985	1982	1986	1009	147
8-9	3.0	0.4	1981	1980	1983	1979	1984	986	134
9-10	3.2	0.4	1978	1976	1980	1975	1981	847	108
10-11	2.1	0.2	1975	1974	1976	1973	1977	981	121
11-12	2.3	0.3	1973	1972	1974	1971	1975	900	109
12-13	4.1	0.4	1970	1968	1972	1967	1973	721	86
13-14	4.3	0.5	1966	1964	1968	1963	1969	610	73
14-15	4.7	0.5	1961	1959	1964	1958	1965	606	73
15-16	5.2	0.6	1956	1954	1959	1953	1960	547	68
16-17	6.3	0.8	1951	1947	1954	1946	1955	502	66
17-18	5.4	0.7	1945	1942	1947	1941	1949	577	80
18-19	6.6	0.9	1939	1935	1942	1934	1943	530	80
19-20	4.9	0.8	1933	1931	1935	1929	1937	702	115
20-21	4.7	0.8	1928	1926	1931	1925	1932	667	117
21-22	5.5	1.0	1923	1920	1926	1919	1927	663	127
22-23	5.1	1.1	1918	1915	1920	1914	1922	666	141
23-24	5.2	1.2	1913	1910	1915	1908	1917	844	197
24-25	2.9	0.7	1909	1907	1910	1906	1911	1096	277
25-26	4.3	1.1	1905	1903	1907	1901	1909	1030	281
26-27	2.1	0.6	1902	1901	1903	1900	1904	1562	456
27-28	2.7	0.8	1899	1898	1901	1897	1902	1311	404
28-29	3.9	1.3	1896	1894	1898	1893	1900	846	280
29-30	4.9	1.8	1892	1889	1894	1887	1896	779	285
30-31	6.5	2.7	1886	1883	1889	1880	1892	582	243
31-32	6.5	3.1	1880	1876	1883	1873	1886	618	300
32-33	6.8	3.8	1873	1870	1876	1866	1880	521	296
33-34	9.8	6.8	1865	1860	1870	1853	1877	419	292

Table 4. Average sedimentation rates for Lake Winnipeg 99-900 cores 4 and 8, using linear and CRS sedimentation models, for top 34-35 cm of cores.

Parameter	Core 4	Core 8	Unit
Linear Model:			
Average linear sedimentation rate	571	858	($g/m^2/yr$)
r^2 value	0.93	0.93	
CRS Model:			
Average CRS sedimentation rate	635	861	($g/m^2/yr$)
Measured Pb-210 flux	107	125	($Bq/m^2/yr$)
Expected Pb-210 flux (determined at ELA)	170	170	($Bq/m^2/yr$)
Focus factor	0.63	0.74	

Table 5. Relative and absolute age markers in Lake Winnipeg 99-900 cores 3, 4 and 8

		Depth (cm)		
Marker		**Core 3**	**Core 4**	**Core 8**
Relative age markers:				
[1]Geochemical	Ca	30	30	30
	Ca	46	41	46
	Ca	69	76	69
	Ca	122	129	119
	Mg	-	31	30
	Mg	-	109	98
	Cd	15	18	20
	Cd	48	45	-
Absolute age markers:				
Cesium-137 peak	Cs-137	-	13	14
[2]Paleomagnetic inclination	I1	126	132	120
[3]Pollen - Salsola rise	Salsola	27	27	28

[1]Geochemical results from Simpson and Thorleifson, this volume.

[2]Paleomagnetic results from King et al., this volume.

[3]Salsola results for core 8 from Anderson, this volume.

Table 6. Chronological models for Lake Winnipeg 99-900 cores 8, 4 and 3

Depth	Age core 8	Age range wt error		Age core 4	Age range wt error		Age core 3	Age range wt error	
(cm)	(years AD)	from	to	(years AD)	from	to	(years AD)	from	to
0-1	1998	1996	1999	1998	1998	1999	1998	1997	1999
1-2	1996	1993	1999	1996	1993	1998	1995	1992	1997
2-3	1994	1992	1996	1993	1991	1996	1993	1991	1995
3-4	1992	1990	1994	1991	1989	1993	1990	1988	1992
4-5	1990	1988	1992	1989	1988	1991	1988	1986	1989
5-6	1988	1986	1990	1987	1985	1990	1984	1982	1987
6-7	1986	1984	1988	1985	1982	1987	1981	1978	1983
7-8	1984	1982	1986	1982	1979	1985	1977	1974	1980
8-9	1981	1979	1984	1978	1976	1981	1972	1970	1975
9-10	1978	1975	1981	1975	1973	1978	1967	1965	1970
10-11	1975	1973	1977	1972	1969	1975	1962	1959	1965
11-12	1973	1971	1975	1968	1965	1971	1956	1954	1959
12-13	1970	1967	1973	1965	1961	1968	1950	1947	1953
13-14	1966	1963	1969	1960	1956	1964	1944	1940	1947
14-15	1961	1958	1965	1955	1951	1958	1936	1935	1942
15-16	1956	1953	1960	1949	1945	1954	1932	1931	1938
16-17	1951	1946	1955	1944	1940	1947	1928	1926	1934
17-18	1945	1941	1949	1939	1935	1942	1924	1922	1930
18-19	1939	1934	1943	1934	1930	1937	1920	1918	1926
19-20	1933	1929	1937	1929	1925	1932	1916	1913	1922
20-21	1928	1925	1932	1924	1920	1928	1912	1909	1918
21-22	1923	1919	1927	1918	1913	1922	1908	1905	1914
22-23	1918	1914	1922	1913	1910	1916	1904	1900	1909
23-24	1913	1908	1917	1909	1905	1912	1900	1896	1905
24-25	1909	1906	1911	1904	1900	1908	1896	1892	1901
25-26	1905	1901	1909	1898	1893	1903	1892	1887	1897
26-27	1902	1900	1904	1892	1887	1897	1888	1883	1893
27-28	1899	1897	1902	1887	1885	1890	1881	1876	1887
28-29	1896	1893	1900	1885	1882	1887	1875	1868	1881
29-30	1892	1887	1896	1881	1878	1885	1868	1861	1874
30-31	1886	1880	1892	1879	1877	1881	1861	1854	1868
31-32	1880	1873	1886	1875	1869	1881	1855	1846	1862
32-33	1873	1866	1880	1868	1859	1877	1848	1839	1856
33-34	1865	1853	1877	1861	1856	1866	1841	1832	1850
34-35	1858	1845	1870	1856	1848	1863	1835	1825	1843
35-36	1850	1837	1863	1849	1841	1857	1828	1817	1837
36-37	1843	1829	1856	1843	1834	1851	1822	1810	1831
37-38	1836	1821	1849	1837	1827	1845	1815	1803	1825
38-39	1828	1813	1842	1830	1820	1839	1808	1795	1819
39-40	1821	1805	1835	1824	1813	1833	1802	1788	1813
40-41	1813	1797	1828	1817	1805	1827	1795	1781	1806
41-42	1806	1788	1822	1811	1798	1821	1788	1773	1800
42-43	1799	1780	1815	1804	1791	1815	1782	1766	1794
43-44	1791	1772	1808	1798	1784	1809	1775	1759	1788
44-45	1784	1764	1801	1791	1777	1803	1768	1752	1782
45-46	1776	1756	1794	1785	1770	1797	1762	1744	1775
46-47	1769	1748	1787	1779	1763	1791	1755	1737	1769

Table 6 continued

Depth (cm)	Age core 8 (years AD)	Age range wt error from	to	Age core 4 (years AD)	Age range wt error from	to	Age core 3 (years AD)	Age range wt error from	to
47-48	1762	1740	1780	1772	1756	1785	1748	1730	1763
48-49	1754	1732	1773	1766	1749	1779	1742	1722	1757
49-50	1747	1724	1766	1759	1742	1773	1735	1715	1751
50-51	1740	1716	1759	1753	1735	1767	1728	1708	1744
51-52	1732	1708	1752	1746	1727	1761	1722	1700	1738
52-53	1725	1700	1745	1740	1720	1755	1715	1693	1732
53-54	1717	1692	1738	1733	1713	1749	1709	1686	1726
54-55	1710	1684	1731	1727	1706	1743	1702	1678	1720
55-56	1703	1676	1724	1720	1699	1737	1695	1671	1713
56-57	1695	1668	1717	1714	1692	1731	1689	1664	1707
57-58	1688	1660	1710	1708	1685	1725	1682	1657	1701
58-59	1680	1652	1703	1701	1678	1719	1675	1649	1695
59-60	1673	1643	1697	1695	1671	1713	1669	1642	1689
60-61	1666	1635	1690	1688	1664	1707	1662	1635	1682
61-62	1658	1627	1683	1682	1656	1701	1655	1627	1676
62-63	1651	1619	1676	1675	1649	1695	1649	1620	1670
63-64	1644	1611	1669	1669	1642	1689	1642	1613	1664
64-65	1636	1603	1662	1662	1635	1683	1635	1605	1658
65-66	1629	1595	1655	1656	1628	1677	1629	1598	1652
66-67	1621	1587	1648	1649	1621	1671	1622	1591	1645
67-68	1614	1579	1641	1643	1614	1665	1615	1584	1639
68-69	1607	1571	1634	1637	1607	1659	1609	1576	1633
69-70	1599	1563	1627	1630	1600	1653	1602	1569	1627
70-71	1592	1555	1620	1624	1593	1647	1596	1562	1621
71-72	1584	1547	1613	1617	1586	1641	1589	1554	1614
72-73	1577	1539	1606	1611	1578	1635	1582	1547	1608
73-74	1570	1531	1599	1604	1571	1629	1576	1540	1602
74-75	1562	1523	1592	1598	1564	1623	1569	1532	1596
75-76	1555	1515	1585	1591	1557	1617	1562	1525	1590
76-77	1548	1506	1579	1585	1550	1611	1556	1518	1583
77-78	1540	1498	1572	1578	1543	1605	1549	1511	1577
78-79	1533	1490	1565	1572	1536	1599	1542	1503	1571
79-80	1525	1482	1558	1566	1529	1593	1536	1496	1565
80-81	1518	1474	1551	1559	1522	1587	1529	1489	1559
81-82	1511	1466	1544	1553	1515	1581	1522	1481	1552
82-83	1503	1458	1537	1546	1508	1575	1516	1474	1546
83-84	1496	1450	1530	1540	1500	1569	1509	1467	1540
84-85	1488	1442	1523	1533	1493	1563	1502	1459	1534
85-86	1481	1434	1516	1527	1486	1557	1496	1452	1528
86-87	1474	1426	1509	1520	1479	1551	1489	1445	1522
87-88	1466	1418	1502	1514	1472	1544	1483	1437	1515
88-89	1459	1410	1495	1507	1465	1538	1476	1430	1509
89-90	1452	1402	1488	1501	1458	1532	1469	1423	1503
90-91	1444	1394	1481	1495	1451	1526	1463	1416	1497
91-92	1437	1386	1474	1488	1444	1520	1456	1408	1491
92-93	1429	1378	1467	1482	1437	1514	1449	1401	1484
93-94	1422	1369	1461	1475	1430	1508	1443	1394	1478

Table 6 continued

Depth (cm)	Age core 8 (years AD)	Age range wt error from	to	Age core 4 (years AD)	Age range wt error from	to	Age core 3 (years AD)	Age range wt error from	to
94-95	1415	1361	1454	1469	1422	1502	1436	1386	1472
95-96	1407	1353	1447	1462	1415	1496	1429	1379	1466
96-97	1400	1345	1440	1456	1408	1490	1423	1372	1460
97-98	1392	1337	1433	1449	1401	1484	1416	1364	1453
98-99	1385	1329	1426	1443	1394	1478	1409	1357	1447
99-100	1378	1321	1419	1436	1387	1472	1403	1350	1441
100-101	1370	1313	1412	1430	1380	1466	1396	1343	1435
101-102	1363	1305	1405	1424	1373	1460	1389	1335	1429
102-103	1356	1297	1398	1417	1366	1454	1383	1328	1422
103-104	1348	1289	1391	1411	1359	1448	1376	1321	1416
104-105	1341	1281	1384	1404	1352	1442	1370	1313	1410
105-106	1333	1273	1377	1398	1344	1436	1363	1306	1404
106-107	1326	1265	1370	1391	1337	1430	1356	1299	1398
107-108	1319	1257	1363	1385	1330	1424	1350	1291	1391
108-109	1311	1249	1356	1378	1323	1418	1343	1284	1385
109-110	1304	1241	1349	1372	1316	1412	1336	1277	1379
110-111	1297	1232	1343	1365	1309	1406	1330	1270	1373
111-112	1289	1224	1336	1359	1302	1400	1323	1262	1367
112-113	1282	1216	1329	1353	1295	1394	1316	1255	1361
113-114	1274	1208	1322	1346	1288	1388	1310	1248	1354
114-115	1267	1200	1315	1340	1281	1382	1303	1240	1348
115-116	1260	1192	1308	1333	1273	1376	1296	1233	1342
116-117	1252	1184	1301	1327	1266	1370	1290	1226	1336
117-118	1245	1176	1294	1320	1259	1364	1283	1218	1330
118-119	1237	1168	1287	1314	1252	1358	1276	1211	1323
119-120	1230	1160	1280	1307	1245	1352	1270	1204	1317
120-121	1223	1152	1273	1301	1238	1346	1263	1196	1311
121-122	1215	1144	1266	1294	1231	1340	1257	1189	1305
122-123	1208	1136	1259	1288	1224	1334	1250	1182	1299
123-124	1201	1128	1252	1282	1217	1328	1243	1175	1292
124-125	1193	1120	1245	1275	1210	1322	1237	1167	1286
125-126	1186	1112	1238	1269	1203	1316	1230	1160	1280
126-127	1178	1104	1231	1262	1195	1310	1223	1153	1274
127-128	1171	1095	1225	1256	1188	1304	1217	1145	1268
128-129	1164	1087	1218	1249	1181	1298	1210	1138	1261
129-130	1156	1079	1211	1243	1174	1292	1203	1131	1255
130-131	1149	1071	1204	1236	1167	1286	1197	1123	1249
131-132	1141	1063	1197	1230	1160	1280	1190	1116	1243
132-133	1134	1055	1190	1223	1153	1274	1183	1109	1237
133-134	1127	1047	1183	1217	1146	1268	1177	1102	1230
134-135	1119	1039	1176	1211	1139	1262	1170	1094	1224
135-136	1112	1031	1169	1204	1132	1256	1163	1087	1218
136-137	1105	1023	1162	1198	1125	1250	1157	1080	1212
137-138	1097	1015	1155	1191	1117	1244	1150	1072	1206
138-139	1090	1007	1148	1185	1110	1238	1144	1065	1200
139-140	1082	999	1141	1178	1103	1232	1137	1058	1193
140-141	1075	991	1134	1172	1096	1226	1130	1050	1187

Table 6 continued

Depth (cm)	Age core 8 (years AD)	Age range wt error from	to	Age core 4 (years AD)	Age range wt error from	to	Age core 3 (years AD)	Age range wt error from	to
141-142	1068	983	1127	1165	1089	1220	1124	1043	1181
142-143	1060	975	1120	1159	1082	1214	1117	1036	1175
143-144	1053	967	1113	1153	1075	1208	1110	1029	1169
144-145	1045	959	1106	1146	1068	1202	1104	1021	1162
145-146	1038	950	1100	1140	1061	1196	1097	1014	1156
146-147	1031	942	1093	1133	1054	1190	1090	1007	1150
14-148	1023	934	1086	1127	1047	1184	1084	999	1144
148-149	1016	926	1079	1120	1039	1178	1077	992	1138
149-150	1009	918	1072	1114	1032	1172	1070	985	1131
150-151	1001	910	1065	1107	1025	1166	1064	977	1125
151-152	994	902	1058	1101	1018	1160	1057	970	1119
152-153	986	894	1051	1094	1011	1154	1051	963	1113
153-154	979	886	1044	1088	1004	1148	1044	955	1107
154-155	972	878	1037	1082	997	1142	1037	948	1100
155-156	964	870	1030	1075	990	1136	1031	941	1094
156-157	957	862	1023	1069	983	1130	1024	934	1088
157-158	949	854	1016	1062	976	1124	1017	926	1082
158-159	942	846	1009	1056	968	1118	1011	919	1076
159-160	935	838	1002	1049	961	1112	1004	912	1069
160-161	927	830	995	1043	954	1106	997	904	1063
161-162	920	822	988	1036	947	1100	991	897	1057

Chronology based on Pb-210 and Cs-137 data, a *Salsola* pollen marker (Anderson, this volume), a paleomagnetic marker I1 (King et al., this volume), and geochemical markers (Simpson and Thorleifson, this volume).

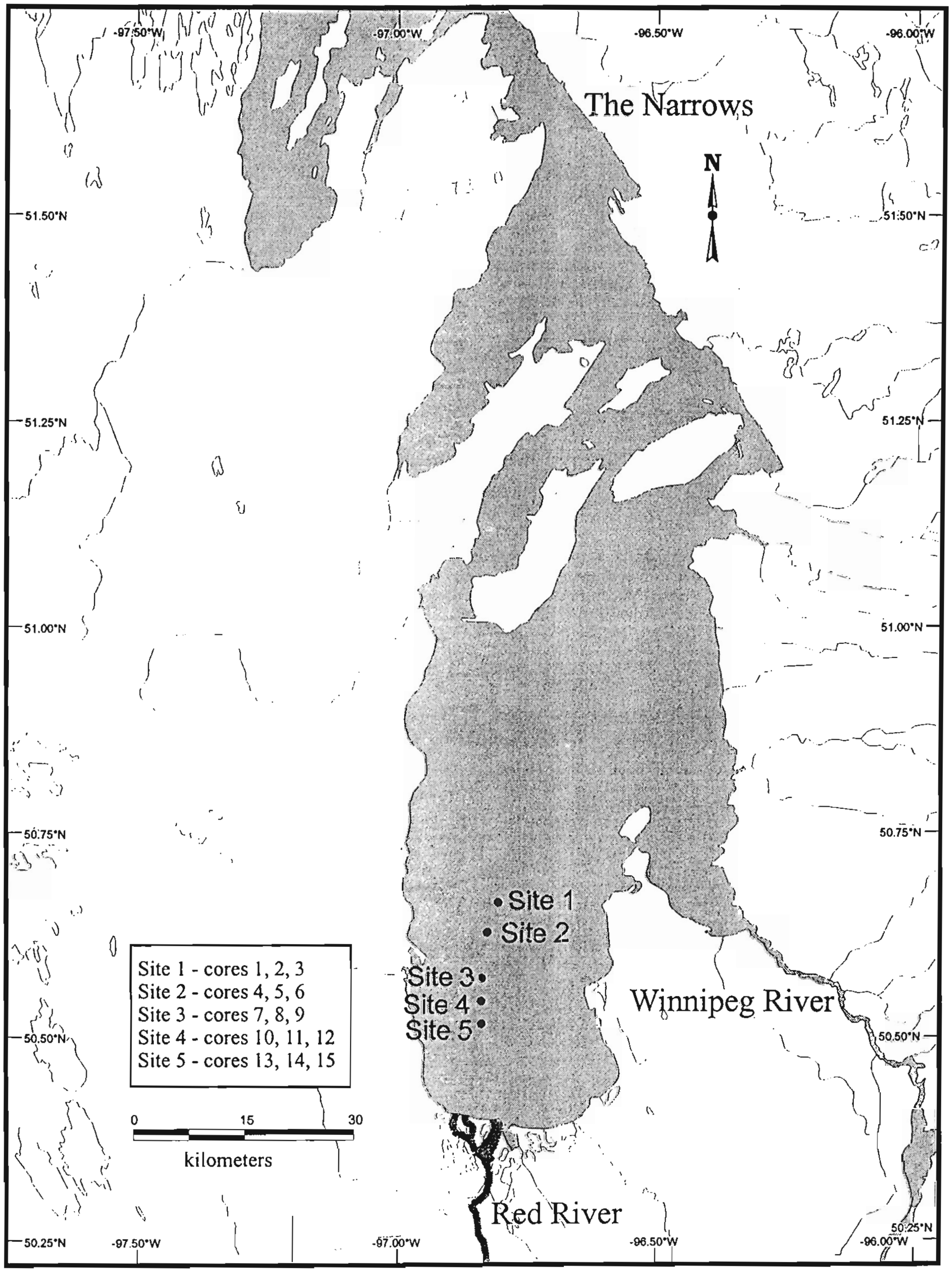

Figure 1. Map of southern Lake Winnipeg showing locations of coring sites

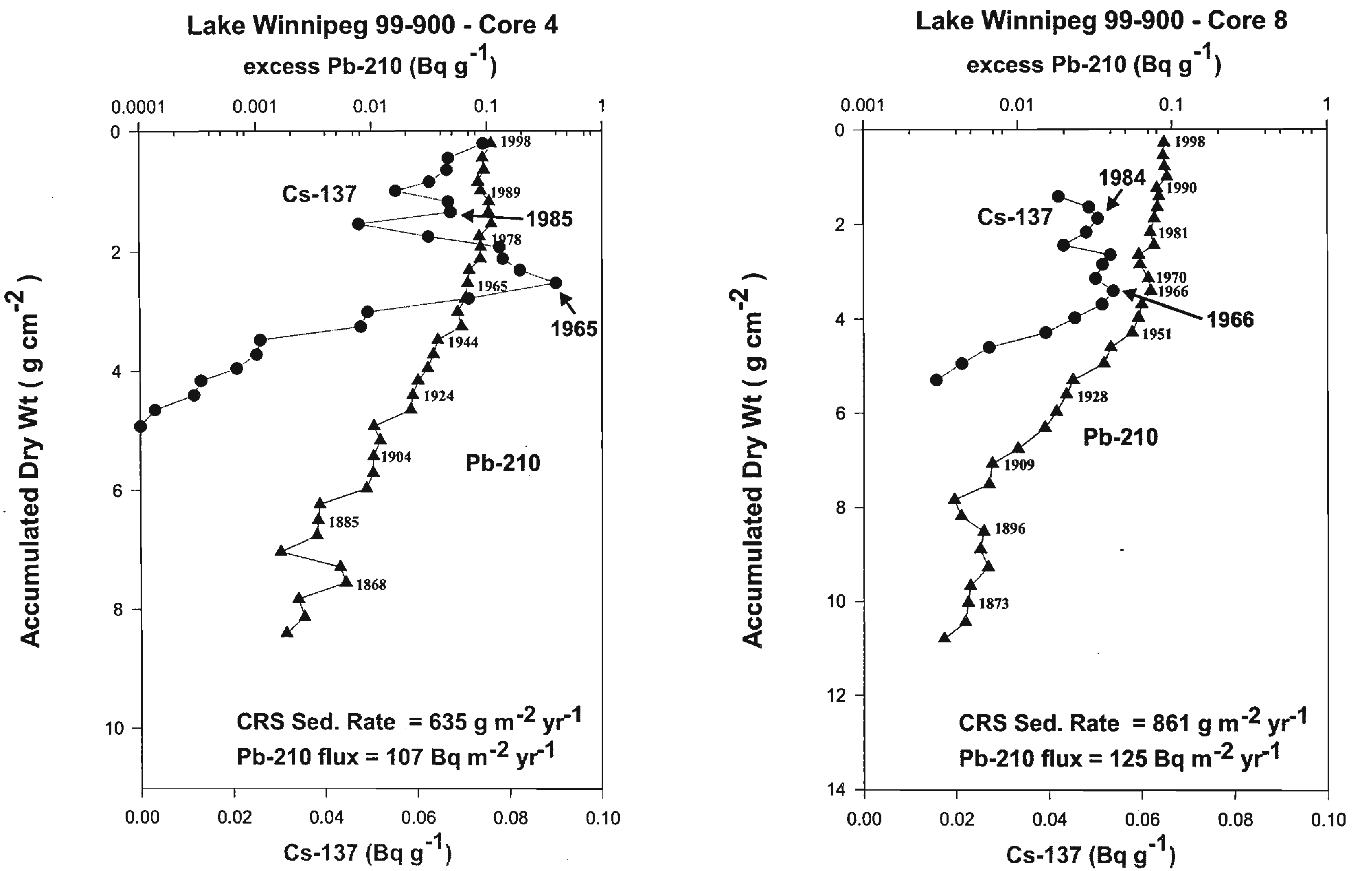

Figure 2. Downcore profiles of Pb-210 and Cs-137 in Lake Winnipeg 99-900 cores 4 and 8

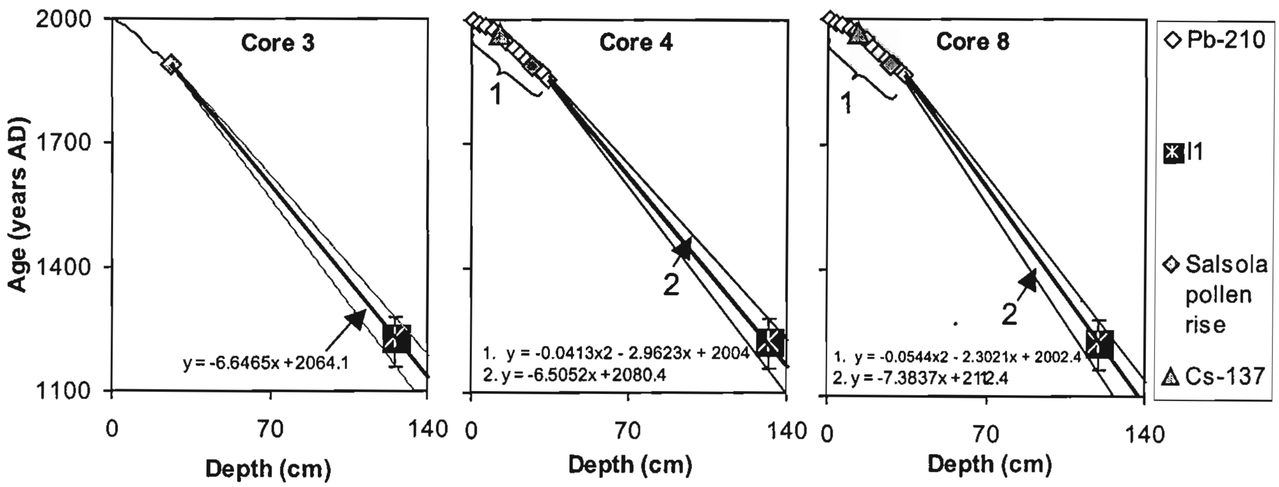

Figure 3. Age versus depth relationship for cores 3, 4, and 8 showing chronological data points derived from Pb-210 and Cs-137, *Salsola* pollen (Anderson, this volume), and paleomagnetic marker I1 (King et al., this volume), as well as core-to-core correlatable Cd, Ca, and Mg relative age markers (Simpson and Thorleifson, this volume). For the top of core 3, chronology was derived from linear interpolation between *Salsola* and a Cd marker at 15 cm depth, and from an average of Pb-210 ages for cores 4 and 8 above this depth. Below the lowest Pb-210 age or *Salsola* in core 3, ages were derived from linear interpolation between pairs of core-to-core correlatable markers, the lowest Pb-210 age or *Salsola*, and I1.

5. Compositional analyses of the cores

5.1 Textural analysis of Lake Winnipeg 99-900 cores 3, 4 and 8

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ABSTRACT

Following the 1997 Red River flood, research addressing the history and controls on the flood hazard included analysis of sediments in Lake Winnipeg to assess flood history and drainage basin evolution. To do so, 15 cores, each about 1.5 m long, were collected from the south basin during a cruise of the Canadian Coast Guard Ship (CCGS) Namao in August 1999, designated Geological Survey of Canada (GSC) cruise 99-900. Textural (grain-size) analysis of 3 of these cores was used to test for the presence of trends and/or events in offshore sedimentation. The sediments consist entirely of silt and clay, averaging 40 % silt and 60 % clay. Decimeter- and centimeter-scale textural variations are evident throughout the cores, exhibiting several silt maxima and numerous layers of greater silt content. Decimeter-scale silt layers are thought to result from subtle shifts in the sediment source areas, perhaps brought about by climatic or other factors, while centimeter-scale layers are thought to result from events such as floods. A steady up-core increase in silt, observable throughout the top 25 cm, is attributable to 20th century changes in land use, particularly the expansion of agriculture and changes in drainage.

INTRODUCTION

The Red River flood of 1997 was a major disaster that drove 103,000 people from their homes. Much is being done, however, to reduce comparable damage and disruption in the future through enhanced dikes and diversions, as well as revised land use and water management practices. The design of these works requires an optimal understanding of the risk. Research therefore has addressed the nature of the largest known flood, in 1826, whether comparable large floods have occurred in recent centuries, and how geomorphic, climatic, land use, and tectonic factors may be changing the flood hazard. These issues are being addressed by examining the geomorphic processes governing evolution of the Red River, archival records of flood history, floodplain stratigraphic records, tree-ring records, changes in valley gradients, and by examining the stratigraphy of Lake Winnipeg sediments (Thorleifson et al., 1998). The coring in Lake Winnipeg, receiving basin of waters from the Red River, was designed to sample sites most likely to have recorded any influx of sediments from the Red River that may have occurred. In addition to recording gradual changes in Red River sediment transport, it was thought that flood events might be recognizable, due to unique properties allowing differentiation from other sediments in the lake, although it was unclear what attribute would best distinguish flood-related sediments. The cores therefore were thoroughly analyzed for chronology, as well as for a broad range of physical, chemical and biological properties to determine which, if any, would record a history of flooding.

In order to test for trends and events, the cores were analyzed for textural (grain-size) characteristics. In lacustrine environments, textural analyses can be used to provide information on sediment provenance, depositional processes, and environmental conditions such as climate change. Previous studies provided information on sediment provenance and depositional processes since sedimentation began in the central south basin 4000 years ago; an increase in the silt content of the uppermost portion of the sediment cores was commonly observed (Last, 1996; Henderson and Last, 1998). Changes in environmental conditions have been recorded in the basin, and include periods of drought and greater precipitation over the past 150 years (Rannie, 1998), the onset of the Little Ice Age in the region in the 15th century A.D. (Gribbin and Lamb, 1978), flood frequency and magnitude reconstructed using tree rings (St. George and Nielsen, 2000), and isostatic rebound and resulting water level rise in the south basin (Lewis et al., 2000; Nielsen, 2000). This chapter aims to provide information on sediment provenance and depositional processes with a refined temporal resolution, and to delineate environmental change over the past millennium using textural characteristics.

LAKE WINNIPEG

Lake Winnipeg, located in central North America, is the eleventh largest lake in the world, having an area of 24,000 km^2 (Hutchinson, 1975). The lake straddles the contact between Paleozoic carbonate rocks to the west and Precambrian igneous and metamorphic rocks of the Canadian Shield to the east. A smaller south basin, approximately 90 km by 40 km, is separated from a north basin, approximately 240 km by 100 km, by a narrow passage known as The Narrows. The glacially-scoured depression in the rocks underlying the lake, with a depth of 50-100 m, is largely filled with fine-grained glacial Lake Agassiz sediments, overlain by up to 15 m of post-glacial Lake Winnipeg sediments (Todd and Lewis, 1996). The bathymetry of the lake is shallow and the bottom is flat, with depths averaging 9 m in the south basin and 16 m in

* Italicized text is repeated in each chapter

the north basin. The lake has a catchment area extending from the Rocky Mountains to very near Lake Superior, including the basins of the Winnipeg, Saskatchewan, Red, Dauphin and numerous smaller rivers. Outflow from the lake is north to Hudson Bay, through the Nelson River. Post-glacial uplift has caused the north end of the basin to rise relative to the south, causing a gradual rise of lake levels that continues at present (Lewis et al., 2000). The mean annual temperature of the region, recorded at Gimli, is +1.4°C, although the continental climate of the region ranges from hot summers to very cold winters. The mean annual precipitation is 50.8 cm. The lake is ice free from early May to late November (Ice Thickness Climatology, 1992) and ice cover from November to May is consistently thick and continuous. The lake waters are poorly stratified to unstratified and during the summer months water temperatures range from +17°C in the north basin to +19.5°C in the south basin (Todd, 1996), hence bottom sediment temperatures are equally warm in mid-summer. The lake supports a commercial fishery, it is a major destination for recreation, and lake levels are regulated to optimize hydroelectric power generation on the Nelson River.

SAMPLING AND ANALYTICAL METHODS

Selection of five sampling sites in the south basin of Lake Winnipeg was based on proximity to the Red River mouth and on the absence of ice scour on sidescan sonar records previously obtained in 1994 on the 94-900 Namao cruise (Lewis et al., this volume) (Figure 1). Site 5 was the southernmost point on the north-south survey line that lacked ice scour. Sampling was conducted in calm weather on August 24, 1999 from the CCGS Namao. Three cores were obtained at each of the five sites using a gravity corer consisting of a 100 kg weightstand over a 2 m steel pipe with a 10 cm diameter plastic liner tube. The length of the cores ranged from 107 cm to 170 cm. The cores were sealed, labelled and transported to Gimli, Manitoba on August 29, where they were refrigerated, and subsequently transported via refrigerated truck to the GSC Atlantic core storage facility in Dartmouth, N.S. A monitoring device attached to the core bundle indicated that the sediments did not exceed a temperature of 19°C at any time during transport. Paleomagnetic and physical property data, determined at the laboratory of Professor J.W. King at the University of Rhode Island, provided information used to select cores that would be representative of the offshore sediments (King et al., this volume). Paleomagnetic profiles indicated more rapid accumulation of sediments at the more northerly sites and hence a higher resolution for examining environmental change. Based on these observations, core 8 (site 3), core 4 (site 2), and core 3 (site 1) were selected as the primary records for detailed study.

Sediments from cores 3, 4 and 8, which are entirely void of sand, were analyzed for eight textural classes of silt and clay, and from these data, mean grain size, standard deviation, % silt and % clay were calculated.

A total of 145 samples from core 3, 162 samples from core 4 and 158 samples from core 8 were sampled and analyzed. The cores were sampled at 1-cm intervals at GSC facilities in Dartmouth. The samples were then shipped in vials to the Freshwater Institute in Winnipeg, where 1 ml subsamples were placed in plastic bags and refrigerated for analysis at GSC Ottawa. Prior to analysis the wet subsamples were soaked in a sodium metaphosphate solution (10 gm/l) for a minimum of 72 hours at the GSC Sedimentology Laboratory in Ottawa. Each sample was collected into a beaker, further diluted with sodium metaphosphate and suspended using a propeller. Subsamples were obtained with disposable syringes and injected into the particle size analyzer.

Analyses were completed using a Lecotract LT-100 particle size analyzer in the GSC Sedimentology Laboratory. According to Jonasz (1991), this equipment is based on the scattering of light rays as they are transmitted through a moving stream of particles suspended in a fluid. Light rays that strike the particles scatter at angles inversely proportional to particle size. A photo detector measures the quantity of light at predetermined angles, producing electrical signals proportional to the quantity of light, the amounts of which are recorded.

Results are reported as weight percentages for 8 classes of silt and clay including <1µm, 1-2µm, 2-4µm, 4-8µm, 8-16µm, 16-31µm, 31-44µm and 44-63µm. Grain-size subdivisions are consistent with those used for previous GSC investigations in 1994 (Last, 1996; Henderson and Last, 1998) and 1996 (Henderson, 2000). Clay is defined as material finer than 4 µm in diameter, silt as material with a diameter of 4 to 63 µm and sand as a material with a diameter of 63 to 2000 µm.

Analytical precision and accuracy were monitored through the analysis of duplicates and a laboratory standard, respectively. Duplicate samples were analyzed, on average, every 13 samples and standards every 12 samples.

RESULTS

Results of the textural analyses for cores 3, 4 and 8 are presented in Tables 1 and 2 and 3, respectively. All of the material was finer than 63µm, and is categorized as either clay or silt, with the exception of a few small pebbles in core 4, which are noted in Table 2. Pebbles occurred at 4 intervals and in each case the pebbles comprise less than 0.02 % of the total sediment weight for the interval. Pebbles were excluded from the calculation of grain-size percentages, as their inclusion would skew the results. These pebbles may have been rafted by ice or floating vegetation or dropped by birds. Mean values were calculated mathematically by the method of moments

(Allen, 1981). Down-core variations in grain size for each of the 8 classes of silt and clay are illustrated for cores 3, 4 and 8 in Figures 2, 3 and 4, respectively. Down-core variations in mean grain-size values and clay-silt content are shown for all cores in Figures 5 and 6.

Quality assurance and quality control

Results of duplicate analyses and analytical precision for cores 3, 4 and 8 are shown in Tables 4, 5 and 6, respectively. A precision of less than 10 % RSD (relative standard deviation) was attained for all of the % silt and % clay results (range: 1.03 % to 7.09 %), but not for all of the individual grain-size classes (range: 0.71 % to 25.00 %). This means that, on average, fluctuations greater than or equal to about 3.5 % in down-core silt and clay are the result of natural processes and not analytical error. Conversely, some of the small variations in grain-size percentages for the 8 classes of grain size may be the result of analytical error. The largest amount of error occurs in the coarsest and finest grain-size classes, so caution should be exercised during interpretation of these data. Precision was slightly better for % silt and % clay results for core 8 than for cores 3 and 4 (core 3, avg. RSD = 5.58 %; core 4, avg. RSD = 4.54 %; core 8, avg. RSD = 1.26 %). These values are all well below 10 % and therefore should not affect interpretation of the results.

The results for the standard, referred to in the laboratory as Chittick, are shown in Tables 7, 8 and 9. This material does not have a certified value, so accuracy cannot be formally determined. However, it was analyzed multiple times throughout each laboratory run and the results compared with previous values to verify that the instrument was functioning in a reproducible manner. Throughout analysis of cores 3, 4 and 8 the mean value of the standard was very consistent and the standard deviations low, indicating consistent laboratory conditions and good reproducibility. However, caution should be exercised when comparing results from these analyses to results from other laboratories, particularly those using a different method of grain-size determination, as accuracy varies amongst methods.

Trends in grain size

Detailed grain-size results

Examination of the eight detailed grain-size classes provides information on down-core grain-size distribution (Figures 2, 3 and 4). Approximately 80 % of the sediment in the cores is classed under the 1-2 µm, 2-4 µm and 4-8 µm classes of clay and very fine silt. About another 15 % of the sediment is classed in the <1 µm and 8-16 µm grain-size classes. On average, less than 5 % of the sediment is classed in the 16-31 µm, 31-44 µm and 44-63 µm classes, showing that the silt present in the sediments consists primarily of fine and very fine silt.

The finer-grained size classes (<1 µm, 1-2 µm and 2-4 µm) exhibit complementary trends to those of the coarser classes (8-16 µm, 16-31 µm, 31-44 µm and 44-63 µm). The transition from one size class to the next is marked by subtle shifts in the amount of material in each class. The 4-8 µm class, which shows less variation than the other fractions, exhibits some of the trends of both the finer and coarser size fractions and appears to be the transition point between the finer and coarser size fractions.

Both centimeter-scale (cm-scale) (1-4 cm thick) and decimeter-scale (dm-scale) (10-30 cm thick) variations are observed in each grain-size class throughout the cores. Cm-scale and dm-scale variations do not appear to consist of a particular grain-size class, except for abrupt and significant cm-scale increases in the percentage of sediment in the 16-31 µm, 31-44 µm and 44-63 µm classes at both 20 cm and 2 cm. Gradual increases in the 8-16 µm, 16-31 µm and 31-44 µm classes, from 20 cm to the top of the core are observed most notably in cores 3 and 4.

Mean grain-size results

Mean grain sizes are 4.29 µm, 4.45 µm and 4.15 µm for cores 3, 4 and 8, respectively. In general, there is little down-core variation in mean grain size for the three cores (Figure 5), with standard deviations of only 1.04, 0.85 and 0.36 for cores 3, 4 and 8, respectively. Cores 3 and 4 have larger standard deviations than core 8 and exhibit the most variation in mean grain size with depth. The down-core plot of core 4 shows a slightly cyclical appearance, with gradual, dm-scale shifts between coarser- and finer-grained material. Core 3 exhibits spikes in mean grain size at depths of 21 cm (max. mean grain size = 10 µm) and 2 cm (max. mean grain size = 8 µm). Cores 3 and 4 exhibit gradual increases in mean grain size in the top 20 cm of the cores.

% clay-silt results

The sediments in cores 3, 4 and 8 consist of clay-sized particles (63 %, 59 % and 59 %, respectively) and silt-sized particles (37 %, 41 % and 41 %, respectively). An examination of the % silt and % clay down-core plots reveals significant variations in grain-size percentages with depth and from core to core (Figure 6). Since the sediments comprise only silt and clay, the % clay plots are the inverse of the % silt plots. Overall, the down-core trends observed for % clay are similar to those for the finest grain-size classes (<1 µm, 1-2 µm and 2-4 µm). Likewise, the down-core trends observed for % silt are similar to those for the coarser grain-size classes (4-8 µm, 8-16 µm, 16-31 µm, 31-44 µm and 44-63 µm). Only a very small percentage of material is classed under the 31-44 µm and 44-63 µm categories (on average <1 %), and therefore does not make an impact on the appearance of the % clay-silt record. Both cm-scale and dm-scale variations are evident in the % clay-silt plots.

An attempt was made to obtain a single plot for each core that accurately represents the down-core variation in texture and clearly demonstrates both cm- and dm-scale variations. In order to do so, a series of 35 plots were constructed, each uniquely combining adjacent grain-size classes or consisting of a single size class (Figure 7). Single grain-size classes, as well as groupings of 2, 3, 4, 5, 6, 7 and 8 classes were constructed and assessed. Single-class and 2- and 3- class groupings are not representative of the variation in texture in the cores, whereas 6- and 7-class groupings tend to have an averaging effect and produce plots that lack variation. The 4- and 5-class groupings do not present these difficulties, and from these classes a 4-63 μm grouping (5 classes) and an 8-63 μm grouping (4 classes) seem to represent the variability in texture and to clearly illustrate both cm- and dm-scale variations. Both groupings are equally useful for recognition of silt layers, and given that the 4-63 μm grouping encompasses the range defined as % silt for these and previous Lake Winnipeg cores, this grouping was used as the basis for subsequent cm- and dm-scale silt characterizations.

Decimeter-scale silt variations

Decimeter-scale variations in silt do not appear to follow a cyclic pattern with a regular periodicity (Figure 8). Rather, the variations are subtle shifts in silt content, comprising 10 to 30 cm-thick layers of enhanced or depressed silt content, best displayed by a multi-point moving mean of % silt. Although several moving means of % silt content were tested, a 15-point moving mean seemed to be most representative of dm-scale variations as 13- and 11-point moving means were influenced to a significant extent by cm-scale variations, and records based on 17- and 19-point means lacked detail.

Overall, the cores exhibit somewhat different patterns of dm-scale variations, and core-to-core correlation is limited in portions of the cores. The lowermost 60 cm of the cores exhibit the most core-to-core variability in dm-scale trends. A prominent peak between 95 and 75 cm in core 4 does not appear to have an equivalent counterpart in the other two cores. Decimeter-scale trends exhibit minima at depths of 30-40 cm, 55-70 cm and 50-65 cm in cores 3, 4 and 8, respectively, which may be correlatable amongst the cores. These minima are followed by rapid up-core increases in all three cores. For core 3, this increase continues to the top of the core. For core 4, the increase continues in a stepwise manner to the top of the core. For core 8, the increase is followed by a stepwise decrease in % silt.

Centimeter-scale silt layers

Superimposed upon dm-scale trends are cm-scale layers of greater silt content. These layers, 1-4 cm thick, are present throughout the cores, with the top of core 3 providing the best example of a sequence of well-defined silt layers (Figure 9). Three layers at the top of core 3 occur at depths of 0-2 cm, 4-7 cm, and 9-11 cm, and have a 6-15 % increase in silt above background. Other prominent layers occur at various depths throughout the cores (Figure 9). In addition, there are several other layers of varying prominence throughout the cores. In general, there is a fair degree of variation between the cores in the occurrence of cm-scale variations. For example, in cores 3 and 4, the cm-scale layers are prominent at the tops of the cores, whereas in core 8, the layers are most prominent in the lower half of the core. Several prominent layers present in a single core do not appear to have counterparts in the other two cores. There does not appear to be an equal number of equivalent layers in each core and hence the cores lack a one-to-one correlation of cm-scale layers.

DISCUSSION

Previous textural studies of Lake Winnipeg sediments

Textural studies of lake-bottom sediments from Lake Winnipeg were previously carried out by Kushnir (1971), Penner and Swedlo (1974), Brunskill and Graham (1979), Last (1996), and Henderson and Last (1998).

Kushnir (1971) examined the bathymetry of the south basin and the grain-size characteristics and mineralogy of 60 bottom-sediment grab samples from the south basin. The basin has a maximum depth of approximately 12 meters, and while water depth increases quite rapidly away from the east and west shores, there is a more gradual increase away from the mouths of the Red and Winnipeg rivers. The grain-size analyses indicate that more than 70 % of the surface sediments in the south basin are clay size (<4 μm) and clay content increases towards the center of the basin (up to 95 %). Kushnir determined that the mineralogy of the south basin clays is quite homogenous and consists of montmorillonite, illite, kaolinite and chlorite, as well as quartz, dolomite, feldspar and others. He also determined that diagenesis of the clay minerals derived from Cretaceous Shales in southwestern is insignificant.

Penner and Swedlo (1974) determined the proportions of sediment derived from what they considered the only two significant sources of sediment to the south basin, the Red River and shoreline erosion. They discounted contributions from the Winnipeg River, as it passes through several lakes along its course, removing much of the suspended sediment load prior to entering Lake Winnipeg. There is, however, no suspended sediment data for the Winnipeg River downstream from these lakes to confirm this. Penner and Swedlo (1974) estimated that the Red River contributes an estimated 83 % (2.3 M tonnes/yr) of the sediment input to the south basin by weight, with shoreline erosion accounting for the remaining 17 % of the sediment (0.51 M tonnes/yr), determined from historic rates of shoreline erosion and suspended sediment data. Whereas > 90 % of Red River suspended sediments consist of silt and clay (Glavic et al., 1988), the sediment derived from shoreline erosion of Lake Winnipeg consists of about 55 % clay and silt and 45 % sand and gravel (Penner and Swedlo, 1974).

Brunskill and Graham (1979) examined grain-size characteristics, mineralogy, water content as well as both inorganic and organic geochemistry of sediments obtained from surface grab samples, 1-2 m cores in Lake Winnipeg, as well as both suspended and bottom sediments in the Red River. Their grain-size and mineralogy results were similar to those found by Kushnir (1971). They found no obvious relationship between graphic parameters of Lake Winnipeg sediment particle size distribution (mean, standard deviation, skewness and kurtosis) and depositional processes.

During the first phase (1994) of the Lake Winnipeg Project, textural analyses (along with other physical, mineralogical and geochemical analyses) were competed on 13 long cores (2-8 m), 8 short cores (<1 m) and 31 bottom sediment grab samples from the north and south basins of Lake Winnipeg (Last, 1996). The study was conducted to address the regional geologic history of the basin and provide information on variations in sediment sources and depositional environments related to basin configuration, climate and catchment area. Slightly finer sediments were observed in the south basin compared with the north basin and sediments fined-upward from the base of the cores to the middle and coarsened-upward near the top of the cores (Henderson and Last, 1998). Sediments in some of the cores simply coarsened upward from the base of the cores to the top. The finer grain size observed in the south basin was attributed to the greater input of fluvial-derived sediments compared to shoreline erosion-derived sediments. Sediments in the north basin are largely derived from shoreline erosion of sand and gravel beaches. The fining-upward sequence is attributed to a greater contribution from river inputs and a lesser contribution from shoreline erosion following low lake levels (north basin) or dry conditions (south basin) 4000 years ago. The grain-size increase in the top 95 cm (AD 1100) of most cores suggests an increase in the rate of sedimentation, a change in water level or a change in sediment source, and was not attributed to anthropogenic causes.

The cored sediments examined here, which belong to the Lake Winnipeg sequence and consist of post-glacial lacustrine muds (Todd and Lewis, 1996; Lewis and Todd, 1996), are approximately 1000 years old, on the basis of radiochemistry, paleomagnetic dating, palynology and radiocarbon dating (Wilkinson and Simpson, this volume).

INTERPRETATION

The relationship between depositional site and textural properties

The dominance of clay- and silt-sized particles indicates that low-energy conditions prevailed offshore during the past 1000 years. Textural properties do vary somewhat with distance from the shoreline. Cores 4 and 8 are closer to the mouth of the Red River and may have a greater proportion of sediments derived from the Red River compared with core 3. Paleomagnetic inclination data shows that the distance between sites results in significant differences in sedimentation rates (King et al., this volume). For instance, cores sampled at sites 4 and 5 have about half the sediment accumulation rate as cores at sites 2 and 3 (including cores 4 and 8), while cores at site 1 (including core 3) have the greatest rate of sediment accumulation. Hence, the more northern cores accumulate sediment more rapidly than southern cores. Lake sediments closer to the mouth of the Red River therefore may be affected by re-suspension of sediments, resulting in less sediment accumulation in the south.

The absence of an increase in silt at the top of core 8, similar to the trends in other cores, is unclear. Examination of the paleomagnetic inclination record shows dissimilar patterns in core 8 versus cores 3 and 4 in the upper portion of the core (King et al., this volume). However, examination of the inorganic geochemistry record (Simpson and Thorleifson, this volume) and the Pb-210 age dates (Wilkinson and Simpson, this volume) indicate that the sediment column was intact and in chronological order following coring. Hence, the origin of this finer-grained material is unclear, and could be attributed to either analytical error or physical disruption of the sediments.

Anthropogenic effects

Increases in % silt in the top 20 cm of cores 3 and 4 coincide with, and seem likely to be the result of land use changes in the early 20th century. These changes include increased agricultural activity and changes in drainage patterns and may be responsible for enhanced runoff and erosion, hence enhanced energy levels and sediment-carrying capacity of the Red River.

Origin of dm- and cm-scale variations

The dm-scale variations observed in the down-core plots could be attributed to cycles in climatic conditions. During wet climatic conditions the degree of erosion and sediment transport may increase, while the reverse may be true for dry climatic conditions. As a result, coarser-grained sediment may be deposited during wetter climatic conditions and finer-grained sediment during dryer conditions. This effect would likely be enhanced for a wetter period that immediately follows a drier interval, as an increase in material susceptible to erosion would become available during periods of low precipitation. On the other hand, it is conceivable that factors such as storm frequency could be significant.

Some of the periods of time associated with dm-scale variations correspond with periods of distinct climatic conditions, documented by Longley (1977) and St. George and Nielsen (2001), while others have no relation to periods of distinct climatic conditions. There was a weak correlation between drier periods and enhanced silt content. For example, the intervals AD 1430-1520 and AD 1670-1775 are documented as drier periods and correspond with increased silt contents. This is contrary to the findings of Campbell (1998), who found that drier periods correspond with decreased silt contents. Overall, there is no consistent correlation between silt content and warmer or drier climates. Cm-scale variations seem most likely to be the result of more rapid events, such as Red River flooding.

CONCLUSIONS

- The sediments consist of silt (~40 %) and clay (~60 %).

- Both cm-scale (1-4 cm) and dm-scale (10-30 cm) variations in grain size are present in all three cores.

- Cm-scale siltier layers, consisting of 6-15 % greater silt than background levels in otherwise finer-grained sediments, were identified in the cores and could be caused by floods.

- Dm-scale siltier layers evident in the cores do not reveal a consistent relationship between climate and grain size. Increases in the mean grain size and the silt content occurred in the top 25 cm of two of the cores is perhaps attributed to enhanced runoff caused by 20th century land-use practices.

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Table 1. Texture of samples from Lake Winnipeg 99-900 core 3

Depth	Size Fraction (μm) (Reported as percentage of <2000μm)								Grain Size Summary		Mean	St. Dev.
cm	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Silt	% Clay	μm	μm
0-1	1.98	3.67	9.71	17.26	24.39	24.27	14.35	4.37	57.01	42.99	8.58	6.65
1-2	1.00	2.53	8.97	16.99	24.17	25.38	15.74	5.22	53.66	46.34	7.51	5.69
2-3	0.00	1.21	6.38	12.63	20.72	29.40	20.69	8.97	40.94	59.06	5.47	4.09
3-4	0.00	1.33	6.62	13.82	22.80	28.56	19.03	7.84	44.57	55.43	5.76	4.26
4-5	0.00	1.63	7.27	14.78	23.99	27.80	17.77	6.76	47.67	52.33	6.14	4.53
5-6	0.00	1.43	6.92	14.96	24.68	27.77	17.89	6.35	47.99	52.01	6.04	4.40
6-7	0.00	1.48	6.21	13.92	26.25	28.09	17.68	6.37	47.86	52.14	5.88	4.06
7-8	0.00	1.19	5.39	11.75	23.50	29.60	20.23	8.34	41.83	58.17	5.30	3.64
8-9	0.00	1.01	4.91	10.88	23.11	30.22	21.23	8.64	39.91	60.09	5.04	3.39
9-10	0.00	1.35	6.09	13.86	25.74	27.98	18.11	6.87	47.04	52.96	5.78	4.03
10-11	0.00	1.53	6.65	14.43	25.18	27.53	17.80	6.88	47.79	52.21	5.99	4.28
11-12	0.96	1.25	4.32	10.11	22.73	29.86	20.74	10.03	39.37	60.63	5.66	3.45
12-13	0.00	1.27	5.49	11.91	24.31	29.74	19.58	7.70	42.98	57.02	5.40	3.67
13-14	0.00	1.06	4.83	12.15	26.45	30.09	18.86	6.56	44.49	55.51	5.31	3.49
14-15	0.00	0.95	4.32	11.38	26.28	30.54	19.55	6.98	42.93	57.07	5.09	3.29
15-16	0.00	1.35	4.94	11.53	26.44	30.32	19.00	6.42	44.26	55.74	5.39	3.46
16-17	0.00	0.79	3.83	11.48	27.65	30.85	19.19	6.21	43.75	56.25	5.00	3.18
17-18	0.85	1.11	3.63	9.67	24.14	31.02	20.94	8.63	39.41	60.59	5.41	3.17
18-19	4.25	4.92	6.58	9.52	20.08	27.66	19.17	7.82	45.35	54.65	10.34	8.84
19-20	3.29	3.74	5.92	9.66	20.34	28.76	20.00	8.29	42.95	57.05	9.17	6.16
20-21	1.28	1.55	3.92	9.30	23.41	31.29	21.16	8.09	39.47	60.53	6.16	3.38
21-22	0.00	0.81	3.52	10.34	26.76	31.83	20.25	6.49	41.43	58.57	4.81	3.00
22-23	0.00	0.81	3.29	10.17	27.25	31.90	20.19	6.39	41.52	58.48	4.77	2.95
23-24	0.00	0.66	3.09	10.19	27.62	32.25	20.27	5.92	41.56	58.44	4.70	2.90
24-25	0.00	1.22	3.54	9.33	26.28	33.02	20.68	5.93	40.37	59.63	4.87	2.90
25-26	0.00	0.70	2.79	8.65	25.74	33.31	21.89	6.92	37.88	62.12	4.44	2.68
26-27	0.00	0.53	2.31	7.48	24.07	34.23	23.16	8.22	34.39	65.61	4.10	2.46
27-28	0.00	0.72	3.18	9.55	26.62	33.30	20.79	5.84	40.07	59.93	4.66	2.82
28-29	0.00	0.83	3.35	9.71	26.28	33.08	20.82	5.93	40.17	59.83	4.73	2.88
29-30	0.00	0.91	3.64	10.45	26.94	32.49	20.12	5.45	41.94	58.06	4.91	3.02
30-31	0.00	0.57	2.66	8.71	25.47	33.31	22.23	7.05	37.41	62.59	4.36	2.66
31-32	0.00	0.71	3.28	10.39	26.71	31.93	20.66	6.32	41.09	58.91	4.73	2.97

Table 1 continued

Depth	Size Fraction (μm) (Reported as percentage of <2000μm)								Grain Size Summary		Mean	St. Dev.
cm	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Silt	% Clay	μm	μm
32-33	0.00	0.98	4.07	11.56	27.50	31.42	19.36	5.11	44.11	55.89	5.14	3.23
33-34	0.00	0.72	3.09	9.46	25.90	32.39	21.58	6.86	39.17	60.83	4.58	2.83
34-35	0.00	0.45	2.15	8.12	25.77	33.93	22.72	6.86	36.49	63.51	4.17	2.52
35-36	0.00	0.46	2.23	8.28	25.69	33.63	22.65	7.06	36.66	63.34	4.20	2.56
36-37	0.00	0.15	1.24	6.70	25.08	34.76	24.20	7.87	33.17	66.83	3.71	2.26
37-38	0.00	0.00	0.57	5.60	24.03	36.00	25.57	8.23	30.20	69.80	3.38	2.06
38-39	0.00	0.34	1.70	7.28	25.46	34.47	23.31	7.44	34.78	65.22	3.95	2.38
39-40	0.00	0.00	0.91	6.95	26.52	36.06	23.21	6.35	34.38	65.62	3.69	2.24
40-41	0.00	0.00	0.78	5.91	24.16	36.09	25.21	7.85	30.85	69.15	3.46	2.10
41-42	0.00	0.34	1.84	7.85	25.96	34.13	22.87	7.01	35.99	64.01	4.05	2.46
42-43	0.00	0.62	2.46	7.91	25.80	34.12	22.28	6.81	36.79	63.21	4.29	2.55
43-44	0.00	0.33	2.04	8.68	26.85	33.80	21.97	6.33	37.90	62.10	4.21	2.58
44-45	0.00	0.40	2.45	9.73	27.44	33.10	20.89	5.99	40.02	59.98	4.40	2.71
45-46	0.00	0.40	2.41	9.49	27.37	33.28	20.97	6.08	39.67	60.33	4.40	2.71
46-47	0.00	0.42	2.52	9.66	27.42	32.84	21.04	6.10	40.02	59.98	4.44	2.76
47-48	0.00	0.42	2.55	9.80	27.15	32.50	20.96	6.62	39.92	60.08	4.44	2.79
48-49	0.00	0.48	2.95	10.84	27.75	32.09	20.07	5.82	42.02	57.98	4.67	2.95
49-50	0.00	0.48	2.97	11.09	28.34	32.16	19.75	5.21	42.88	57.12	4.73	2.96
50-51	0.00	0.47	2.94	11.20	28.67	32.10	19.52	5.10	43.28	56.72	4.74	2.97
51-52	0.00	0.35	2.43	10.14	27.90	33.49	20.44	5.25	40.82	59.18	4.48	2.77
52-53	0.00	0.42	2.83	11.02	27.82	32.07	20.07	5.77	42.09	57.91	4.64	2.95
53-54	0.00	0.00	2.14	9.75	27.81	33.40	21.00	5.90	39.70	60.30	4.25	2.68
54-55	0.00	0.00	2.16	9.90	28.19	33.71	20.70	5.34	40.25	59.75	4.30	2.68
55-56	0.00	0.32	2.48	10.97	29.16	33.56	19.32	4.19	42.93	57.07	4.62	2.84
56-57	0.00	0.00	1.59	9.85	28.39	34.45	21.04	4.68	39.83	60.17	4.18	2.61
57-58	0.00	0.00	1.79	10.29	28.95	33.97	20.42	4.58	41.03	58.97	4.28	2.68
58-59	0.00	0.00	2.09	9.97	28.45	34.05	20.69	4.75	40.51	59.49	4.31	2.67
59-60	0.00	0.00	1.38	8.29	26.67	34.56	22.63	6.47	36.34	63.66	3.91	2.44
60-61	0.00	0.00	0.86	7.30	26.22	35.88	23.40	6.34	34.38	65.62	3.70	2.27
61-62	0.00	0.00	0.80	6.96	25.65	35.96	23.99	6.64	33.41	66.59	3.64	2.23
62-63	0.00	0.00	0.98	7.56	26.07	34.79	23.28	7.32	34.61	65.39	3.72	2.33
63-64	0.00	0.00	1.42	8.03	25.86	33.86	23.24	7.59	35.31	64.69	3.84	2.43

Table 1 continued

Depth	Size Fraction (µm) (Reported as percentage of <2000µm)								Grain Size Summary		Mean	St. Dev.
cm	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Silt	% Clay	µm	µm
64-65	0.00	0.32	2.42	10.50	27.71	32.59	20.65	5.81	40.95	59.05	4.47	2.83
65-66	0.00	0.00	1.65	9.85	28.56	33.58	20.98	5.38	40.06	59.94	4.18	2.64
66-67	0.00	0.00	2.26	10.66	29.12	33.06	19.88	5.02	42.04	57.96	4.42	2.78
67-68	0.00	0.00	1.47	8.46	27.03	34.33	22.41	6.30	36.96	63.04	3.95	2.47
68-69	0.00	0.00	1.43	8.71	27.60	34.35	21.89	6.02	37.74	62.26	4.00	2.49
69-70	0.00	0.00	1.07	9.01	28.27	34.65	21.66	5.34	38.35	61.65	3.98	2.49
70-71	0.00	0.00	1.61	9.79	28.51	33.65	21.05	5.39	39.91	60.09	4.17	2.63
71-72	0.00	0.00	1.51	9.31	27.79	34.01	21.78	5.60	38.61	61.39	4.07	2.56
72-73	0.00	0.00	1.08	9.09	27.95	34.51	21.89	5.48	38.12	61.88	3.97	2.50
73-74	0.00	0.00	1.87	9.88	28.18	33.15	21.04	5.88	39.93	60.07	4.21	2.67
74-75	0.00	0.00	0.86	8.03	27.62	35.25	22.53	5.71	36.51	63.49	3.83	2.37
75-76	0.00	0.00	1.42	8.44	27.73	34.41	21.81	6.19	37.59	62.41	3.97	2.46
76-77	0.00	0.00	1.02	8.42	28.05	34.50	21.89	6.12	37.49	62.51	3.90	2.43
77-78	0.00	0.00	1.40	8.64	27.83	34.32	21.79	6.02	37.87	62.13	3.99	2.49
78-79	0.00	0.00	0.96	8.29	27.79	34.65	22.21	6.10	37.04	62.96	3.87	2.41
79-80	0.00	0.40	2.08	8.19	26.52	33.86	22.08	6.87	37.19	62.81	4.18	2.54
80-81	0.00	0.00	0.87	6.93	26.52	35.57	23.45	6.66	34.32	65.68	3.68	2.25
81-82	0.00	0.30	1.73	7.57	26.41	34.35	22.65	6.99	36.01	63.99	4.01	2.43
82-83	0.00	0.15	1.67	7.58	26.76	34.70	22.69	6.45	36.16	63.84	3.97	2.40
83-84	0.00	0.00	0.88	6.74	25.65	35.11	24.04	7.58	33.27	66.73	3.61	2.24
84-85	0.00	0.32	1.75	7.80	26.74	34.12	22.42	6.85	36.61	63.39	4.06	2.46
85-86	0.00	0.32	1.76	7.83	26.88	34.39	22.38	6.44	36.79	63.21	4.08	2.46
86-87	0.00	0.35	1.88	7.98	26.83	34.01	22.06	6.89	37.04	62.96	4.11	2.49
87-88	0.00	0.36	1.88	7.67	26.15	34.06	22.56	7.32	36.06	63.94	4.06	2.46
88-89	0.00	0.38	1.90	7.47	25.86	34.16	22.80	7.43	35.61	64.39	4.04	2.43
89-90	0.00	0.34	1.69	6.94	24.80	34.11	23.68	8.44	33.77	66.23	3.88	2.35
90-91	0.00	0.00	1.23	6.54	24.19	34.07	24.76	9.21	31.96	68.04	3.58	2.25
91-92	0.00	0.00	0.85	6.40	24.53	34.14	24.80	9.28	31.78	68.22	3.50	2.21
92-93	0.00	0.00	0.37	5.55	25.08	36.01	24.92	8.07	31.00	69.00	3.39	2.08
93-94	0.00	0.00	0.82	6.43	25.19	34.70	24.23	8.63	32.44	67.56	3.54	2.21
94-95	0.00	0.00	0.75	5.74	23.91	34.89	25.41	9.30	30.40	69.60	3.40	2.11
95-96	0.00	0.00	0.82	6.42	25.24	35.06	24.51	7.95	32.48	67.52	3.55	2.20

Table 1 continued

Depth	Size Fraction (µm) (Reported as percentage of <2000µm)								Grain Size Summary		Mean	St. Dev.
cm	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Silt	% Clay	µm	µm
96-97	0.00	0.00	1.27	7.41	27.32	35.01	22.62	6.37	36.00	64.00	3.84	2.34
97-98	0.00	0.00	1.27	7.26	27.14	35.10	22.85	6.38	35.67	64.33	3.81	2.32
98-99	0.00	0.00	1.32	7.46	26.28	34.50	23.22	7.22	35.06	64.94	3.79	2.36
99-100	0.00	0.33	1.94	8.87	27.77	32.96	21.83	6.30	38.91	61.09	4.23	2.61
100-101	0.00	0.00	1.78	8.53	27.47	33.15	22.12	6.95	37.78	62.22	4.04	2.54
101-102	0.00	0.00	1.23	7.43	27.19	34.58	22.99	6.58	35.85	64.15	3.82	2.35
102-103	0.00	0.15	1.80	8.62	28.30	33.51	21.49	6.13	38.87	61.13	4.15	2.55
103-104	0.00	0.36	1.94	8.66	28.62	34.24	20.93	5.25	39.58	60.42	4.28	2.56
104-105	0.00	0.39	1.89	7.94	27.43	34.59	21.73	6.03	37.65	62.35	4.16	2.48
105-106	0.00	0.33	1.62	6.86	25.80	34.82	23.22	7.35	34.61	65.39	3.91	2.33
106-107	0.00	0.00	0.74	5.44	23.84	35.64	25.33	9.01	30.02	69.98	3.38	2.07
107-108	0.00	0.00	0.35	4.88	22.46	35.66	26.90	9.75	27.69	72.31	3.19	1.97
108-109	0.00	0.00	0.40	5.22	23.04	35.88	26.19	9.27	28.66	71.34	3.27	2.01
109-110	0.00	0.15	1.42	6.58	24.85	35.18	24.11	7.71	33.00	67.00	3.74	2.26
110-111	0.00	0.15	1.47	6.99	25.88	35.17	23.28	7.06	34.49	65.51	3.83	2.31
111-112	0.00	0.00	1.31	7.34	26.77	35.37	22.77	6.44	35.42	64.58	3.82	2.33
112-113	0.00	0.00	1.07	7.21	26.72	35.25	23.10	6.65	35.00	65.00	3.75	2.31
113-114	0.00	0.00	0.82	6.35	25.06	35.32	24.51	7.94	32.23	67.77	3.54	2.19
114-115	0.00	0.35	2.08	7.79	25.10	34.16	23.17	7.35	35.32	64.68	4.06	2.46
115-116	0.00	0.00	1.36	6.52	23.24	34.53	25.04	9.31	31.12	68.88	3.57	2.21
116-117	0.00	0.34	1.70	6.07	23.27	35.59	24.58	8.45	31.38	68.62	3.76	2.19
117-118	0.00	0.00	0.70	5.23	23.24	36.12	25.60	9.11	29.17	70.83	3.34	2.03
118-119	0.00	0.00	0.36	4.92	23.32	36.86	25.68	8.86	28.60	71.40	3.26	1.97
119-120	0.00	0.00	0.38	5.26	24.00	36.45	25.25	8.66	29.64	70.36	3.32	2.02
120-121	0.00	0.00	0.72	5.37	23.90	35.96	25.12	8.93	29.99	70.01	3.38	2.06
121-122	0.00	0.00	0.36	5.08	24.13	37.15	25.39	7.89	29.57	70.43	3.32	1.99
122-123	0.00	0.00	0.35	5.10	23.84	36.29	25.53	8.89	29.29	70.71	3.29	2.01
123-124	0.00	0.00	0.72	5.89	25.16	36.32	24.33	7.58	31.77	68.23	3.50	2.12
124-125	0.00	0.00	0.85	6.42	25.24	35.64	24.18	7.67	32.51	67.49	3.56	2.19
125-126	0.00	0.00	0.85	6.52	24.89	34.59	24.42	8.73	32.26	67.74	3.54	2.22
126-127	0.00	0.32	1.72	7.82	26.70	33.64	22.55	7.25	36.56	63.44	4.04	2.47
127-128	0.00	0.34	1.78	8.00	27.35	33.97	21.82	6.74	37.47	62.53	4.11	2.49

Table 1 continued

Depth	Size Fraction (μm) (Reported as percentage of <2000μm)								Grain Size Summary		Mean	St. Dev.
cm	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Silt	% Clay	μm	μm
128-129	0.00	0.00	1.27	7.51	27.33	34.88	22.55	6.46	36.11	63.89	3.84	2.36
129-130	0.00	0.00	1.30	7.49	27.27	34.57	22.41	6.96	36.06	63.94	3.84	2.37
130-131	0.00	0.00	0.80	6.64	26.24	35.74	23.87	6.71	33.68	66.32	3.63	2.21
131-132	0.00	0.00	0.84	7.05	27.31	35.68	22.82	6.30	35.20	64.80	3.72	2.27
132-133	0.00	0.00	0.77	6.52	26.27	35.84	23.66	6.94	33.56	66.44	3.61	2.20
133-134	0.00	0.00	0.39	5.92	25.47	36.21	24.54	7.47	31.78	68.22	3.45	2.11
134-135	0.00	0.00	0.39	5.75	25.49	36.88	24.55	6.94	31.63	68.37	3.45	2.07
135-136	0.00	0.00	0.42	6.13	26.32	36.57	23.96	6.60	32.87	67.13	3.52	2.13
136-137	0.00	0.00	1.23	6.74	25.70	35.05	23.70	7.58	33.67	66.33	3.69	2.26
137-138	0.00	0.31	1.85	8.14	26.95	33.83	22.47	6.45	37.25	62.75	4.11	2.51
138-139	0.00	0.00	0.79	6.27	24.61	35.62	24.85	7.86	31.67	68.33	3.51	2.17
139-140	0.00	0.00	0.80	6.30	25.03	35.88	24.40	7.59	32.13	67.87	3.54	2.17
140-141	0.00	0.00	0.40	5.67	24.76	36.40	25.06	7.71	30.83	69.17	3.40	2.07
141-142	0.00	0.00	0.42	6.10	26.28	36.57	24.04	6.59	32.80	67.20	3.52	2.13
142-143	0.00	0.00	0.35	5.61	26.11	37.22	24.20	6.51	32.07	67.93	3.46	2.06
143-144	0.00	0.00	0.35	5.62	25.67	36.47	24.70	7.19	31.64	68.36	3.43	2.07
144-145	0.00	0.00	0.40	6.36	26.79	35.78	23.94	6.73	33.55	66.45	3.55	2.17
									Mean **37** St.Dev. **5.03**	Mean **63** St.Dev. **5.03**	Mean **4.29** St.Dev. **1.04**	

Table 2. Texture of samples from Lake Winnipeg 99-900 core 4

Depth	Size Fraction (μm) (Reported as percentage of <2000μm)								Grain Size Summary		Mean	St. Dev.
cm	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Silt	% Clay	μm	μm
0-1	0.00	1.79	7.31	16.43	27.14	28.06	15.27	4.00	52.67	47.33	6.52	4.57
1-2	0.00	1.81	7.28	16.20	26.56	28.64	15.48	4.03	51.85	48.15	6.48	4.58
2-3	1.08	2.22	7.38	17.22	27.33	26.91	14.18	3.68	55.23	44.77	7.28	5.02
3-4	1.12	2.31	7.73	17.55	27.04	26.47	14.04	3.74	55.75	44.25	7.42	5.18
4-5	0.00	1.64	7.27	15.38	25.01	28.96	16.44	5.30	49.30	50.70	6.27	4.55
5-6	0.00	1.62	7.50	15.63	24.44	29.41	16.28	5.12	49.19	50.81	6.32	4.65
6-7	0.00	1.56	6.84	15.44	25.62	29.52	16.31	4.71	49.46	50.54	6.20	4.39
7-8	0.00	1.40	6.63	17.10	28.22	28.16	14.81	3.68	53.35	46.65	6.34	4.35
8-9	0.00	1.40	6.41	15.57	27.02	29.22	16.22	4.16	50.40	49.60	6.12	4.22
9-10	0.00	1.52	6.88	16.44	27.22	28.41	15.49	4.04	52.06	47.94	6.34	4.41
10-11	0.00	1.35	6.42	15.87	27.63	29.11	15.66	3.96	51.27	48.73	6.15	4.21
11-12	0.00	1.36	6.33	16.13	28.94	28.93	14.73	3.58	52.76	47.24	6.22	4.16
12-13	0.00	2.53	7.35	14.45	26.48	29.18	15.98	4.03	50.81	49.19	6.59	4.54
13-14	0.00	1.65	6.64	16.08	29.80	28.73	14.15	2.95	54.17	45.83	6.42	4.20
14-15	0.00	1.48	6.27	15.60	30.08	28.86	14.36	3.35	53.43	46.57	6.24	4.05
15-16	0.00	1.38	6.03	15.24	30.08	29.24	14.64	3.39	52.73	47.27	6.13	3.95
16-17	0.00	1.01	4.47	12.92	29.98	30.97	16.74	3.91	48.38	51.62	5.47	3.38
17-18	0.00	1.06	4.55	13.13	30.21	30.91	16.41	3.73	48.95	51.05	5.53	3.42
18-19	0.00	1.02	4.36	12.78	30.42	31.04	16.54	3.84	48.58	51.42	5.45	3.34
19-20	0.00	0.89	3.98	12.12	30.50	31.35	17.11	4.05	47.49	52.51	5.27	3.20
20-21	0.00	0.75	3.40	11.05	29.48	32.32	18.53	4.47	44.68	55.32	4.97	3.01
21-22	0.00	0.65	3.08	11.18	30.44	32.37	18.04	4.24	45.35	54.65	4.92	2.96
22-23	0.00	0.62	2.90	10.58	30.15	32.86	18.55	4.34	44.25	55.75	4.81	2.87
23-24	0.00	0.51	2.49	9.87	29.85	33.44	19.42	4.42	42.72	57.28	4.61	2.74
24-25	0.00	0.65	2.65	9.45	29.14	34.17	19.68	4.26	41.89	58.11	4.64	2.71
25-26	0.00	0.89	3.39	10.14	29.21	33.36	18.74	4.27	43.63	56.37	4.94	2.90
26-27	0.00	0.39	1.97	8.30	28.61	34.95	20.93	4.85	39.27	60.73	4.28	2.51
27-28	0.00	0.38	1.98	9.17	30.10	34.26	19.75	4.36	41.63	58.37	4.41	2.60
28-29	0.00	0.37	1.96	9.42	30.81	34.12	19.30	4.02	42.56	57.44	4.46	2.62
29-30	0.00	0.57	2.48	9.79	30.60	33.62	18.89	4.05	43.44	56.56	4.66	2.73
30-31	0.00	0.38	2.01	9.52	30.74	34.30	19.06	3.99	42.65	57.35	4.48	2.63
31-32	0.00	0.37	1.97	9.32	30.02	34.27	19.79	4.26	41.68	58.32	4.42	2.62
32-33	0.00	0.34	1.86	8.80	29.33	34.57	20.56	4.54	40.33	59.67	4.31	2.55

Table 2 continued

Depth	Size Fraction (μm) (Reported as percentage of <2000μm)								Grain Size Summary		Mean	St. Dev.
cm	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Silt	% Clay	μm	μm
33-34	0.00	0.37	2.04	9.68	30.63	34.01	19.21	4.06	42.72	57.28	4.49	2.65
34-35	0.00	0.47	2.61	11.27	31.88	32.94	17.52	3.31	46.23	53.77	4.84	2.86
35-36	0.00	0.45	2.43	10.69	31.10	33.23	18.31	3.79	44.67	55.33	4.71	2.80
36-37	0.00	0.39	2.18	9.97	30.35	33.67	19.27	4.17	42.89	57.11	4.54	2.71
37-38	0.00	0.33	1.90	9.40	30.24	34.28	19.67	4.18	41.87	58.13	4.41	2.61
38-39	0.00	0.38	2.19	9.98	30.15	33.62	19.39	4.29	42.70	57.30	4.53	2.71
39-40	0.00	0.35	2.00	9.51	29.85	34.15	19.81	4.33	41.71	58.29	4.43	2.64
40-41	0.00	0.36	1.92	9.15	29.60	34.66	20.04	4.27	41.03	58.97	4.38	2.59
41-42	0.00	0.32	1.80	8.88	29.68	34.47	20.42	4.43	40.68	59.32	4.31	2.55
42-43	0.00	0.51	2.34	8.45	28.69	35.08	20.33	4.60	39.99	60.01	4.42	2.56
43-44	0.00	0.34	2.09	9.62	30.42	34.26	19.10	4.17	42.47	57.53	4.48	2.65
44-45	0.00	0.00	1.49	8.70	30.02	35.78	19.89	4.12	40.21	59.79	4.14	2.46
45-46	0.00	0.34	2.17	9.92	30.34	33.88	19.10	4.25	42.77	57.23	4.51	2.69
46-47	0.00	0.38	2.39	10.41	30.58	33.60	18.58	4.06	43.76	56.24	4.63	2.76
47-48	0.00	0.35	2.28	10.68	31.06	33.29	18.38	3.96	44.37	55.63	4.63	2.78
48-49	0.00	0.32	1.96	9.18	30.04	34.82	19.56	4.12	41.50	58.50	4.39	2.58
49-50	0.00	0.39	2.41	10.19	29.91	33.70	19.08	4.32	42.90	57.10	4.59	2.75
50-51	0.00	0.36	2.19	9.25	28.63	34.14	20.26	5.17	40.43	59.57	4.39	2.64
51-52	0.00	0.34	2.05	8.98	28.95	34.58	20.37	4.73	40.32	59.68	4.35	2.59
52-53	0.00	0.36	2.09	8.76	28.28	34.72	20.62	5.17	39.49	60.51	4.32	2.57
53-54	0.00	0.31	1.78	8.07	27.86	34.89	21.56	5.53	38.02	61.98	4.15	2.47
54-55	0.00	0.00	1.38	7.73	27.72	35.23	21.85	6.09	36.83	63.17	3.91	2.38
55-56	0.00	0.00	1.58	8.05	28.76	35.38	21.03	5.20	38.39	61.61	4.04	2.42
56-57	0.00	0.00	0.82	6.94	28.23	36.89	22.13	4.99	35.99	64.01	3.77	2.23
57-58	0.00	0.00	0.81	6.84	27.24	35.59	22.94	6.58	34.89	65.11	3.69	2.25
58-59	0.00	0.00	0.78	6.83	27.30	35.43	23.01	6.65	34.91	65.09	3.68	2.25
59-60	0.00	0.00	0.43	6.57	26.90	35.70	23.63	6.77	33.90	66.10	3.58	2.20
60-61	0.00	0.00	0.81	6.90	27.66	35.60	22.65	6.38	35.37	64.63	3.71	2.26
61-62	0.00	0.00	0.58	6.71	27.42	36.03	22.89	6.37	34.71	65.29	3.64	2.22
62-63	0.00	0.00	0.00	4.31	23.11	37.83	26.28	8.47	27.42	72.58	3.15	1.88
63-64	0.00	0.00	0.00	5.21	27.36	38.97	23.29	5.17	32.57	67.43	3.45	1.99
64-65	0.00	0.00	0.37	5.82	26.81	37.43	23.32	6.25	33.00	67.00	3.52	2.09
65-66	0.00	0.00	0.35	5.49	25.97	37.24	24.13	6.82	31.81	68.19	3.44	2.05

Table 2 continued

Depth	Size Fraction (µm) (Reported as percentage of <2000µm)								Grain Size Summary		Mean	St. Dev.
cm	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Silt	% Clay	µm	µm
66-67	0.00	0.00	0.38	6.11	26.95	36.86	23.71	5.99	33.44	66.56	3.55	2.13
67-68	0.00	0.00	0.39	6.19	26.79	36.91	23.79	5.93	33.37	66.63	3.55	2.13
68-69	0.00	0.00	0.92	7.81	28.60	35.32	21.94	5.41	37.33	62.67	3.86	2.36
69-70	0.00	0.00	1.42	9.01	30.45	34.66	20.09	4.37	40.88	59.12	4.15	2.51
70-71	0.00	0.33	2.07	10.07	30.49	33.46	19.30	4.28	42.96	57.04	4.50	2.71
71-72	0.00	0.75	2.79	9.05	29.15	34.46	19.56	4.24	41.74	58.26	4.67	2.69
72-73	0.00	0.00	1.50	8.91	29.36	34.90	20.52	4.81	39.77	60.23	4.12	2.50
73-74	0.00	0.00	1.12	8.09	29.31	35.74	20.94	4.80	38.52	61.48	3.97	2.38
74-75	0.00	0.00	0.92	7.85	29.50	35.87	21.06	4.80	38.27	61.73	3.91	2.35
*75-76	0.00	0.40	2.35	10.16	30.36	33.60	18.90	4.23	43.27	56.73	4.59	2.74
76-77	0.00	0.46	2.68	10.88	30.31	32.90	18.47	4.30	44.33	55.67	4.74	2.86
77-78	0.00	0.57	3.15	12.08	31.32	32.16	17.01	3.71	47.12	52.88	5.02	3.03
78-79	0.00	0.63	3.35	12.35	31.05	31.91	16.99	3.72	47.38	52.62	5.10	3.09
79-80	0.00	0.62	3.50	13.01	31.35	31.23	16.60	3.69	48.48	51.52	5.19	3.18
80-81	0.00	0.53	3.02	12.02	31.53	32.10	17.08	3.72	47.10	52.90	4.98	3.01
81-82	0.00	0.73	3.63	12.48	31.01	31.60	16.84	3.71	47.85	52.15	5.20	3.16
82-83	0.00	0.49	2.74	10.97	30.57	33.31	17.99	3.93	44.77	55.23	4.79	2.86
83-84	0.00	0.91	3.72	11.67	30.79	32.57	17.02	3.32	47.09	52.91	5.22	3.08
84-85	0.00	0.44	2.61	11.28	31.69	33.37	17.33	3.28	46.02	53.98	4.82	2.85
85-86	0.00	0.59	3.35	12.93	31.84	31.53	16.55	3.21	48.71	51.29	5.17	3.13
86-87	0.00	0.32	2.03	9.74	30.38	34.04	19.26	4.23	42.47	57.53	4.46	2.66
87-88	0.00	0.00	1.88	9.39	30.63	34.52	19.39	4.19	41.90	58.10	4.31	2.58
88-89	0.00	0.44	2.66	11.37	31.10	32.58	17.85	4.00	45.57	54.43	4.80	2.90
89-90	0.00	0.61	3.20	11.72	30.06	31.56	18.39	4.46	45.59	54.41	4.95	3.05
90-91	0.00	0.33	2.03	9.46	28.68	33.03	20.57	5.90	40.50	59.50	4.35	2.68
91-92	0.00	0.40	2.56	11.74	31.03	32.04	18.16	4.07	45.73	54.27	4.79	2.94
92-93	0.00	0.33	2.19	10.48	30.29	33.25	19.13	4.33	43.29	56.71	4.56	2.77
93-94	0.00	0.62	4.04	16.05	32.69	29.41	14.55	2.64	53.40	46.60	5.63	3.49
94-95	0.00	0.71	3.90	14.75	33.19	30.39	14.53	2.53	52.55	47.45	5.54	3.34
95-96	0.00	0.74	3.82	14.16	33.60	30.55	14.58	2.55	52.32	47.68	5.50	3.27
96-97	0.00	0.79	3.56	11.91	31.16	31.83	17.04	3.71	47.42	52.58	5.16	3.09
97-98	0.00	0.45	2.55	10.27	30.32	33.06	18.92	4.43	43.59	56.41	4.65	2.79
98-99	0.00	0.36	1.97	8.39	28.47	34.13	20.85	5.83	39.19	60.81	4.25	2.54

Table 2 continued

Depth	Size Fraction (μm) (Reported as percentage of <2000μm)								Grain Size Summary		Mean	St. Dev.
cm	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Silt	% Clay	μm	μm
*99-100	0.00	0.15	1.71	7.81	28.12	34.70	21.49	6.02	37.79	62.21	4.06	2.43
100-101	0.00	0.16	1.66	7.37	27.52	34.88	22.03	6.38	36.71	63.29	3.99	2.38
101-102	0.00	0.00	1.27	7.24	27.67	35.38	22.17	6.27	36.18	63.82	3.84	2.32
102-103	0.00	0.00	0.80	6.52	27.25	36.20	22.90	6.33	34.57	65.43	3.66	2.20
103-104	0.00	0.00	0.83	7.34	29.01	35.97	21.54	5.31	37.18	62.82	3.82	2.30
104-105	0.00	0.00	0.80	6.99	28.38	35.18	22.32	6.33	36.17	63.83	3.74	2.28
105-106	0.00	0.00	0.77	6.52	26.93	35.28	23.27	7.23	34.22	65.78	3.62	2.22
106-107	0.00	0.00	0.79	6.57	26.85	35.09	23.23	7.47	34.21	65.79	3.63	2.24
107-108	0.00	0.00	0.78	6.40	27.02	35.86	23.26	6.68	34.20	65.80	3.63	2.20
108-109	0.00	0.00	0.77	6.53	27.59	36.03	22.82	6.26	34.89	65.11	3.67	2.21
109-110	0.00	0.00	0.83	6.87	27.55	35.42	22.85	6.48	35.25	64.75	3.70	2.26
110-111	0.00	0.00	0.76	6.69	27.35	35.60	23.06	6.54	34.80	65.20	3.67	2.23
111-112	0.00	0.00	0.42	6.40	27.38	36.30	23.15	6.35	34.20	65.80	3.59	2.17
112-113	0.00	0.00	0.90	7.16	27.59	34.40	22.69	7.26	35.65	64.35	3.72	2.32
113-114	0.00	0.00	1.30	7.93	29.29	34.84	21.24	5.40	38.52	61.48	3.98	2.40
114-115	0.00	0.32	1.67	8.03	29.89	35.22	20.33	4.54	39.91	60.09	4.22	2.45
115-116	0.00	0.34	1.70	7.88	29.36	35.95	20.35	4.42	39.28	60.72	4.21	2.42
116-117	0.00	0.00	0.81	6.80	28.16	36.63	22.05	5.55	35.77	64.23	3.74	2.23
117-118	0.00	0.00	0.90	7.42	28.76	36.04	21.51	5.37	37.08	62.92	3.83	2.30
118-119	0.00	0.00	1.27	7.63	28.82	35.75	21.40	5.13	37.72	62.28	3.94	2.35
119-120	0.00	0.00	1.63	7.37	27.36	35.13	22.21	6.30	36.36	63.64	3.93	2.36
*120-121	0.00	0.00	0.88	6.99	26.74	35.34	23.38	6.67	34.61	65.39	3.69	2.27
121-122	0.00	0.00	0.41	5.97	25.80	35.78	24.34	7.70	32.18	67.82	3.46	2.13
122-123	0.00	0.00	0.38	6.04	27.03	37.37	23.34	5.84	33.45	66.55	3.55	2.11
123-124	0.00	0.00	0.15	4.94	25.35	38.36	24.75	6.45	30.44	69.56	3.35	1.96
124-125	0.00	0.00	0.33	5.55	26.98	38.18	23.36	5.60	32.86	67.14	3.51	2.05
125-126	0.00	0.00	0.36	5.83	26.74	37.55	23.62	5.90	32.93	67.07	3.52	2.09
126-127	0.00	0.00	0.37	5.99	26.69	37.11	23.51	6.33	33.05	66.95	3.52	2.11
127-128	0.00	0.00	0.39	6.64	28.48	36.99	22.41	5.09	35.51	64.49	3.67	2.19
128-129	0.00	0.00	0.36	6.48	29.30	37.49	21.75	4.62	36.14	63.86	3.69	2.17
*129-130	0.00	0.00	0.91	8.23	31.29	35.62	19.80	4.15	40.43	59.57	4.02	2.38
130-131	0.00	0.00	0.82	7.91	31.00	35.70	20.22	4.35	39.73	60.27	3.96	2.35
131-132	0.00	0.00	1.39	9.00	31.18	34.79	19.41	4.23	41.57	58.43	4.18	2.50

Table 2 continued

Depth	Size Fraction (μm) (Reported as percentage of <2000μm)								Grain Size Summary		Mean	St. Dev.
cm	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Silt	% Clay	μm	μm
132-133	0.00	0.00	1.50	9.70	32.10	34.10	18.59	4.01	43.30	56.70	4.30	2.58
133-134	0.00	0.00	1.37	9.49	32.52	34.57	18.55	3.50	43.38	56.62	4.28	2.54
134-135	0.00	0.00	0.94	8.36	30.28	34.98	20.68	4.76	39.58	60.42	3.98	2.42
135-136	0.00	0.00	0.93	8.19	29.91	34.63	21.07	5.27	39.03	60.97	3.94	2.41
136-137	0.00	0.00	0.87	7.27	26.97	34.51	23.12	7.26	35.11	64.89	3.71	2.32
137-138	0.00	0.00	0.88	7.83	28.59	34.60	21.92	6.18	37.30	62.70	3.84	2.38
138-139	0.00	0.48	1.97	7.30	27.42	34.99	21.70	6.14	37.17	62.83	4.16	2.42
139-140	0.00	0.00	1.23	7.37	27.77	35.08	22.25	6.30	36.37	63.63	3.84	2.35
140-141	0.00	0.31	1.79	8.40	29.28	34.88	20.67	4.67	39.78	60.22	4.25	2.50
141-142	0.00	0.00	1.42	8.44	29.45	35.50	20.55	4.64	39.31	60.69	4.07	2.44
142-143	0.00	0.33	1.84	8.77	30.21	34.54	19.82	4.49	41.15	58.85	4.34	2.55
143-144	0.00	0.00	0.92	7.98	30.12	35.54	20.67	4.77	39.02	60.98	3.94	2.37
144-145	0.00	0.00	0.82	7.32	28.68	35.79	21.83	5.56	36.82	63.18	3.80	2.30
145-146	0.00	0.00	0.87	7.73	29.36	35.67	21.42	4.95	37.96	62.04	3.88	2.34
146-147	0.00	0.00	0.76	7.08	28.61	36.04	22.05	5.46	36.45	63.55	3.77	2.27
147-148	0.00	0.00	0.76	7.26	29.14	36.10	21.76	4.98	37.16	62.84	3.81	2.28
148-149	0.00	0.00	0.88	7.79	29.29	35.13	21.43	5.48	37.96	62.04	3.87	2.36
149-150	0.00	0.00	0.87	7.57	28.96	35.26	21.73	5.61	37.40	62.60	3.84	2.34
150-151	0.00	0.00	1.31	8.42	29.59	35.00	20.89	4.79	39.32	60.68	4.04	2.45
151-152	0.00	0.00	0.43	7.19	28.97	36.50	21.95	4.96	36.59	63.41	3.74	2.25
152-153	0.00	0.00	0.75	6.96	27.46	35.45	22.91	6.47	35.17	64.83	3.69	2.27
153-154	0.00	0.00	1.27	8.11	28.26	34.80	21.87	5.69	37.64	62.36	3.94	2.42
154-155	0.00	0.33	1.92	9.47	30.56	34.17	19.39	4.16	42.28	57.72	4.43	2.62
155-156	0.00	0.15	1.71	8.73	30.37	34.86	19.89	4.29	40.96	59.04	4.26	2.52
156-157	0.00	0.00	1.35	9.02	31.03	34.60	19.66	4.34	41.40	58.60	4.16	2.51
157-158	0.00	0.31	1.92	9.73	31.01	33.98	18.85	4.20	42.97	57.03	4.46	2.65
158-159	0.00	0.31	1.79	8.62	29.47	34.45	20.23	5.13	40.19	59.81	4.27	2.54
159-160	0.00	0.00	0.87	7.62	28.92	35.57	21.55	5.47	37.41	62.59	3.85	2.34
160-161	0.00	0.00	0.76	7.28	29.41	36.15	21.51	4.89	37.45	62.55	3.83	2.29
161-162	0.00	0.00	1.28	8.14	29.20	35.56	20.99	4.83	38.62	61.38	4.00	2.41
									Mean **41** St.Dev. **5.85**	Mean **59** St.Dev. **5.85**	Mean **4.45** St.Dev. **0.85**	

***Sample depths of 75-76, 99-100, 120-121 and 129-130 had minor amounts of pebbles, which are not included in the above calculations.**

Table 3. Texture of samples from Lake Winnipeg 99-900 core 8

Depth	Size Fraction (μm) (Reported as percentage of <2000μm)								Grain Size Summary		Mean	St. Dev.
cm	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Silt	% Clay	μm	μm
0-1	0.00	1.16	4.27	8.57	21.41	33.19	22.60	8.80	35.41	64.59	4.71	2.91
1-2	0.00	0.69	3.13	8.26	21.89	33.91	23.15	8.97	33.97	66.03	4.30	2.64
2-3	0.00	0.52	2.66	8.01	22.51	34.12	23.27	8.91	33.70	66.30	4.15	2.55
3-4	0.00	0.56	2.76	7.77	22.52	33.92	23.39	9.08	33.61	66.39	4.16	2.53
4-5	0.00	0.51	2.51	7.54	22.78	34.44	23.45	8.77	33.34	66.66	4.09	2.46
5-6	0.00	0.60	2.72	7.10	20.97	34.10	24.71	9.80	31.39	68.61	4.04	2.41
6-7	0.00	0.49	2.47	7.47	22.00	34.34	24.03	9.20	32.43	67.57	4.03	2.43
7-8	0.00	0.00	1.31	6.13	22.23	36.36	24.93	9.04	29.67	70.33	3.51	2.11
8-9	0.00	0.45	2.39	7.65	22.74	34.47	23.54	8.76	33.23	66.77	4.05	2.45
9-10	0.00	0.47	2.38	7.98	23.81	33.70	23.00	8.66	34.64	65.36	4.12	2.53
10-11	0.00	0.46	2.47	9.34	27.29	33.74	20.33	6.37	39.56	60.44	4.42	2.70
11-12	0.00	0.65	3.27	9.52	24.71	33.36	21.03	7.46	38.15	61.85	4.55	2.84
12-13	0.00	0.49	2.58	8.96	26.31	34.28	20.83	6.55	38.34	61.66	4.39	2.65
13-14	0.00	0.71	3.15	9.85	26.48	33.38	20.04	6.39	40.19	59.81	4.66	2.86
14-15	0.00	0.82	3.38	9.77	26.29	33.09	20.17	6.48	40.26	59.74	4.73	2.90
15-16	0.00	0.73	3.46	10.45	27.08	32.53	19.44	6.31	41.72	58.28	4.81	2.98
16-17	0.00	0.66	3.03	9.92	28.08	33.41	19.43	5.47	41.69	58.31	4.70	2.83
17-18	0.00	0.59	3.04	10.44	28.61	32.52	19.27	5.53	42.68	57.32	4.74	2.90
18-19	0.00	0.36	2.02	9.59	31.15	34.03	18.79	4.06	43.12	56.88	4.49	2.64
19-20	0.00	0.41	2.16	9.34	29.70	33.63	19.75	5.01	41.61	58.39	4.45	2.65
20-21	0.00	0.00	1.33	9.07	31.58	34.89	19.15	3.98	41.98	58.02	4.19	2.49
21-22	0.00	0.33	1.84	9.44	31.31	34.12	18.97	3.99	42.92	57.08	4.44	2.60
22-23	0.00	0.00	0.84	7.71	29.26	35.01	21.77	5.41	37.81	62.19	3.86	2.35
23-24	0.00	0.00	0.90	8.21	30.11	35.15	20.93	4.70	39.22	60.78	3.96	2.39
24-25	0.00	0.00	0.40	7.54	30.92	35.49	21.12	4.53	38.86	61.14	3.84	2.31
25-26	0.00	0.00	0.78	8.89	31.87	34.43	19.94	4.09	41.54	58.46	4.06	2.46
26-27	0.00	0.00	0.33	5.85	27.86	36.47	23.70	5.79	34.04	65.96	3.54	2.12
27-28	0.00	0.00	0.40	7.03	30.06	36.38	21.57	4.56	37.49	62.51	3.77	2.23
28-29	0.00	0.00	0.88	8.81	32.49	35.10	19.20	3.52	42.18	57.82	4.11	2.43
29-30	0.00	0.00	0.76	8.24	31.54	35.16	20.11	4.19	40.54	59.46	4.00	2.38
30-31	0.00	0.00	0.41	7.98	31.70	35.21	20.41	4.29	40.09	59.91	3.91	2.34
31-32	0.00	0.00	0.43	8.72	29.95	35.05	21.14	4.71	39.10	60.90	3.91	2.43

Table 3 continued

Depth	Size Fraction (μm) (Reported as percentage of <2000μm)								Grain Size Summary		Mean	St. Dev.
cm	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Silt	% Clay	μm	μm
32-33	0.00	0.00	0.41	9.15	32.09	34.75	19.50	4.10	41.65	58.35	4.03	2.47
33-34	0.00	0.00	0.49	9.19	30.59	34.78	20.38	4.57	40.27	59.73	3.99	2.48
34-35	0.00	0.00	0.53	9.84	30.91	33.71	20.23	4.78	41.28	58.72	4.06	2.56
35-36	0.00	0.00	0.49	9.39	30.75	34.31	20.40	4.66	40.63	59.37	4.01	2.50
36-37	0.00	0.00	0.45	9.18	31.05	34.53	20.41	4.38	40.68	59.32	4.00	2.48
37-38	0.00	0.00	0.49	9.53	31.43	34.36	19.89	4.30	41.45	58.55	4.05	2.51
38-39	0.00	0.00	0.40	8.68	30.99	35.03	20.55	4.35	40.07	59.93	3.95	2.42
39-40	0.00	0.00	0.92	9.51	31.18	33.84	20.05	4.50	41.61	58.39	4.11	2.55
40-41	0.00	0.00	1.04	10.59	32.26	33.20	18.82	4.09	43.89	56.11	4.27	2.65
41-42	0.00	0.00	1.04	10.31	32.02	33.31	19.15	4.17	43.37	56.63	4.24	2.63
42-43	0.00	0.00	1.40	11.23	34.14	33.46	16.86	2.91	46.77	53.23	4.50	2.69
43-44	0.00	0.00	0.91	9.99	33.33	34.24	18.21	3.32	44.23	55.77	4.26	2.55
44-45	0.00	0.00	0.84	9.18	32.04	34.67	19.26	4.01	42.06	57.94	4.12	2.49
45-46	0.00	0.00	0.41	7.68	30.45	35.50	21.27	4.69	38.54	61.46	3.83	2.32
46-47	0.00	0.00	0.83	8.80	31.30	34.86	19.88	4.33	40.93	59.07	4.05	2.46
47-48	0.00	0.00	0.77	8.73	31.71	35.02	19.65	4.12	41.21	58.79	4.05	2.44
48-49	0.00	0.00	1.03	10.59	33.62	34.02	17.64	3.10	45.24	54.76	4.35	2.61
49-50	0.00	0.00	0.96	11.53	34.65	33.93	16.34	2.59	47.14	52.86	4.47	2.66
50-51	0.00	0.00	0.89	11.36	34.27	33.79	16.89	2.80	46.52	53.48	4.42	2.65
51-52	0.00	0.00	1.10	11.64	33.60	33.32	17.24	3.10	46.34	53.66	4.45	2.71
52-53	0.00	0.00	0.38	7.90	30.54	36.52	20.40	4.26	38.82	61.18	3.87	2.31
53-54	0.00	0.00	0.38	7.78	30.22	36.03	21.06	4.53	38.38	61.62	3.84	2.31
54-55	0.00	0.00	0.40	8.20	30.97	36.09	20.16	4.18	39.57	60.43	3.91	2.34
55-56	0.00	0.00	0.32	7.10	29.89	36.48	21.46	4.75	37.31	62.69	3.75	2.24
56-57	0.00	0.00	0.00	6.36	29.68	37.17	22.01	4.78	36.04	63.96	3.63	2.15
57-58	0.00	0.00	0.00	6.07	29.50	37.36	22.38	4.69	35.57	64.43	3.60	2.12
58-59	0.00	0.00	0.00	6.62	30.32	36.69	21.82	4.55	36.94	63.06	3.67	2.18
59-60	0.00	0.00	0.00	5.67	28.96	37.43	22.93	5.01	34.63	65.37	3.53	2.09
60-61	0.00	0.00	0.31	7.31	31.04	35.95	20.97	4.42	38.66	61.34	3.81	2.28
61-62	0.00	0.00	0.00	4.06	28.11	38.84	23.85	5.14	32.17	67.83	3.35	1.93
62-63	0.00	0.00	0.73	6.61	29.81	37.24	21.20	4.41	37.15	62.85	3.79	2.19
63-64	0.00	0.00	0.39	8.64	32.53	35.18	19.29	3.97	41.56	58.44	4.01	2.40

Table 3 continued

Depth	Size Fraction (μm) (Reported as percentage of <2000μm)								Grain Size Summary		Mean	St. Dev.
cm	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Silt	% Clay	μm	μm
64-65	0.00	0.00	0.41	8.96	32.17	34.72	19.64	4.10	41.54	58.46	4.02	2.44
65-66	0.00	0.00	0.54	11.27	34.18	32.87	17.83	3.31	45.99	54.01	4.32	2.65
66-67	0.00	0.00	0.42	8.91	31.40	34.61	20.38	4.28	40.73	59.27	3.98	2.44
67-68	0.00	0.00	0.85	10.64	32.87	33.44	18.71	3.49	44.36	55.64	4.28	2.63
68-69	0.00	0.00	0.49	10.81	34.30	33.35	17.88	3.17	45.60	54.40	4.28	2.60
69-70	0.00	0.31	1.97	10.96	32.19	32.61	18.20	3.76	45.43	54.57	4.62	2.78
70-71	0.00	0.00	2.07	11.85	33.58	32.44	16.93	3.13	47.50	52.50	4.68	2.82
71-72	0.00	0.00	1.53	11.05	32.98	33.12	17.96	3.36	45.56	54.44	4.46	2.71
72-73	0.00	0.00	1.30	11.80	33.84	32.60	17.38	3.08	46.94	53.06	4.51	2.75
73-74	0.00	0.00	0.85	9.40	33.01	34.57	18.76	3.41	43.26	56.74	4.18	2.50
74-75	0.00	0.00	0.79	8.61	31.59	35.26	19.79	3.96	40.99	59.01	4.04	2.42
75-76	0.00	0.00	0.46	8.63	32.66	35.53	19.34	3.38	41.75	58.25	4.03	2.39
76-77	0.00	0.00	1.01	10.53	33.59	33.99	17.80	3.08	45.13	54.87	4.34	2.60
77-78	0.00	0.00	0.95	10.61	34.34	33.53	17.49	3.08	45.90	54.10	4.36	2.61
78-79	0.00	0.00	1.73	12.68	33.43	32.01	17.09	3.06	47.84	52.16	4.66	2.87
79-80	0.00	0.00	1.30	11.63	33.32	32.62	17.86	3.27	46.25	53.75	4.47	2.75
80-81	0.00	0.00	0.92	9.94	33.70	34.39	17.92	3.13	44.56	55.44	4.27	2.54
81-82	0.00	0.00	0.40	7.57	31.59	36.05	20.25	4.14	39.56	60.44	3.88	2.30
82-83	0.00	0.60	2.14	8.35	30.51	34.68	19.54	4.18	41.60	58.40	4.47	2.54
83-84	0.00	0.00	0.40	7.11	30.12	36.56	21.18	4.63	37.63	62.37	3.78	2.24
84-85	0.00	0.00	0.34	6.26	28.45	36.39	22.90	5.66	35.05	64.95	3.61	2.16
85-86	0.00	0.00	0.40	7.40	31.03	36.19	20.65	4.33	38.83	61.17	3.84	2.28
86-87	0.00	0.00	0.33	6.46	29.86	36.45	22.04	4.86	36.65	63.35	3.69	2.19
87-88	0.00	0.34	0.72	6.11	28.17	37.15	22.08	5.43	35.34	64.66	3.78	2.17
88-89	0.00	0.00	0.38	6.68	29.76	36.98	21.49	4.71	36.82	63.18	3.72	2.20
89-90	0.00	0.00	0.44	8.07	31.85	35.83	19.76	4.05	40.36	59.64	3.94	2.34
90-91	0.00	0.00	0.62	8.52	32.10	35.81	19.40	3.55	41.24	58.76	4.03	2.38
91-92	0.00	0.00	0.80	8.51	31.44	35.35	19.84	4.06	40.75	59.25	4.03	2.41
92-93	0.00	0.00	0.43	7.68	30.60	36.03	20.88	4.38	38.71	61.29	3.85	2.31
93-94	0.00	0.00	0.40	7.31	30.23	36.22	21.27	4.57	37.94	62.06	3.80	2.27
94-95	0.00	0.00	0.41	7.47	30.70	35.90	20.95	4.57	38.58	61.42	3.83	2.29
95-96	0.00	0.00	0.40	7.30	29.45	35.98	22.00	4.87	37.15	62.85	3.76	2.27

Table 3 continued

Depth	Size Fraction (μm) (Reported as percentage of <2000μm)								Grain Size Summary		Mean	St. Dev.
cm	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Silt	% Clay	μm	μm
96-97	0.00	0.00	1.22	10.22	32.00	33.65	18.88	4.03	43.44	56.56	4.28	2.62
97-98	0.00	0.00	1.14	9.09	30.28	34.01	20.43	5.05	40.51	59.49	4.08	2.52
98-99	0.00	0.37	2.30	14.54	38.38	29.71	12.93	1.77	55.59	44.41	5.27	2.99
99-100	0.00	0.41	2.90	15.56	34.92	29.22	14.45	2.54	53.79	46.21	5.35	3.24
100-101	0.00	0.34	2.05	11.61	32.60	31.90	17.76	3.74	46.60	53.40	4.72	2.86
101-102	0.00	0.00	0.83	8.87	31.18	33.96	20.54	4.62	40.88	59.12	4.03	2.48
102-103	0.00	0.00	0.85	9.42	32.72	33.62	19.33	4.06	42.99	57.01	4.15	2.52
103-104	0.00	0.00	1.94	11.00	32.62	32.68	17.96	3.80	45.56	54.44	4.53	2.75
104-105	0.00	0.00	0.97	10.27	34.32	33.81	17.46	3.17	45.56	54.44	4.33	2.58
105-106	0.00	0.00	0.97	10.45	34.00	33.39	17.91	3.28	45.42	54.58	4.33	2.61
106-107	0.00	0.00	0.46	9.11	33.90	34.41	18.63	3.49	43.47	56.53	4.11	2.46
107-108	0.00	0.00	0.35	7.26	31.10	36.55	20.64	4.10	38.71	61.29	3.83	2.26
108-109	0.00	0.00	0.38	8.24	34.04	35.95	18.30	3.09	42.66	57.34	4.04	2.34
109-110	0.00	0.00	0.41	7.36	30.60	36.13	20.97	4.53	38.37	61.63	3.82	2.28
110-111	0.00	0.00	0.34	7.18	32.32	37.10	19.63	3.43	39.84	60.16	3.88	2.24
111-112	0.00	0.00	0.39	7.60	32.02	36.09	19.88	4.02	40.01	59.99	3.90	2.30
112-113	0.00	0.00	0.36	7.70	33.43	36.46	18.83	3.22	41.49	58.51	3.97	2.29
113-114	0.00	0.00	1.54	11.94	35.56	32.00	16.11	2.85	49.04	50.96	4.64	2.76
114-115	0.00	0.00	0.89	9.00	31.72	34.55	19.71	4.13	41.61	58.39	4.09	2.48
115-116	0.00	0.00	0.34	6.48	28.95	37.23	22.22	4.78	35.77	64.23	3.67	2.17
116-117	0.00	0.00	0.76	7.76	29.46	35.54	21.66	4.82	37.98	62.02	3.87	2.35
117-118	0.00	0.00	0.78	8.91	31.30	34.62	20.07	4.32	40.99	59.01	4.05	2.47
118-119	0.00	0.00	0.43	7.94	30.04	35.37	21.43	4.79	38.41	61.59	3.84	2.35
119-120	0.00	0.00	0.87	7.95	29.51	35.29	21.19	5.19	38.33	61.67	3.90	2.38
120-121	0.00	0.00	0.86	8.74	30.90	35.19	20.10	4.21	40.50	59.50	4.04	2.45
121-122	0.00	0.00	0.79	8.39	30.22	34.58	20.83	5.19	39.40	60.60	3.95	2.44
122-123	0.00	0.00	0.88	8.83	31.14	35.10	19.89	4.16	40.85	59.15	4.06	2.46
123-124	0.00	0.00	0.85	8.96	31.16	34.55	20.01	4.47	40.97	59.03	4.06	2.48
124-125	0.00	0.00	0.89	9.13	31.48	35.00	19.51	3.99	41.50	58.50	4.10	2.48
125-126	0.00	0.00	0.43	7.94	30.31	35.41	21.11	4.80	38.68	61.32	3.86	2.36
126-127	0.00	0.00	0.80	8.44	31.15	35.12	20.21	4.28	40.39	59.61	4.01	2.42
127-128	0.00	0.00	0.89	9.15	31.46	34.26	19.79	4.45	41.50	58.50	4.09	2.51

Table 3 continued

Depth	Size Fraction (µm) (Reported as percentage of <2000µm)								Grain Size Summary		Mean	St. Dev.
cm	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Silt	% Clay	µm	µm
128-129	0.00	0.00	0.94	9.66	31.85	34.44	19.09	4.02	42.45	57.55	4.17	2.55
129-130	0.00	0.00	0.92	9.34	31.58	34.32	19.59	4.25	41.84	58.16	4.12	2.52
130-131	0.00	0.00	0.90	9.27	31.40	34.57	19.65	4.21	41.57	58.43	4.11	2.51
131-132	0.00	0.00	0.44	7.73	30.18	35.70	21.21	4.74	38.35	61.65	3.84	2.33
132-133	0.00	0.00	0.90	9.20	31.17	34.35	19.95	4.43	41.27	58.73	4.09	2.51
133-134	0.00	0.00	1.06	10.74	32.37	33.19	18.63	4.01	44.17	55.83	4.30	2.67
134-135	0.00	0.00	1.55	11.27	32.31	32.62	18.31	3.94	45.13	54.87	4.44	2.76
135-136	0.00	0.00	1.01	10.10	31.64	33.48	19.43	4.34	42.75	57.25	4.20	2.61
136-137	0.00	0.00	0.00	4.94	27.19	38.24	23.93	5.70	32.13	67.87	3.40	2.00
137-138	0.00	0.00	0.36	7.07	29.42	36.06	22.17	4.92	36.85	63.15	3.73	2.26
138-139	0.00	0.00	0.41	7.49	28.56	35.19	22.59	5.76	36.46	63.54	3.73	2.32
139-140	0.00	0.00	0.94	9.26	29.84	34.03	20.72	5.21	40.04	59.96	4.04	2.53
140-141	0.00	0.00	1.46	10.64	31.18	33.50	19.08	4.14	43.28	56.72	4.33	2.69
141-142	0.00	0.00	1.03	9.75	30.46	34.10	20.08	4.58	41.24	58.76	4.13	2.58
142-143	0.00	0.00	2.14	12.56	31.56	31.74	18.03	3.97	46.26	53.74	4.66	2.94
143-144	0.00	0.00	1.60	12.13	31.35	32.29	18.57	4.06	45.08	54.92	4.49	2.86
144-145	0.00	0.00	1.07	10.58	32.95	33.41	18.48	3.51	44.60	55.40	4.32	2.64
145-146	0.00	0.00	1.66	12.32	33.78	31.73	17.22	3.29	47.76	52.24	4.62	2.84
146-147	0.00	0.00	2.09	13.72	32.63	30.42	17.19	3.95	48.44	51.56	4.78	3.05
147-148	0.00	0.00	1.95	14.43	34.12	30.73	15.82	2.95	50.50	49.50	4.88	3.04
148-149	0.00	0.00	0.88	9.38	30.74	34.22	20.19	4.59	41.00	59.00	4.08	2.53
149-150	0.00	0.00	1.03	12.21	35.38	32.29	16.27	2.82	48.62	51.38	4.55	2.75
150-151	0.00	0.00	2.39	15.05	33.44	30.06	15.99	3.07	50.88	49.12	5.01	3.15
151-152	0.00	0.00	2.35	13.77	31.79	30.70	17.50	3.89	47.91	52.09	4.82	3.08
152-153	0.00	0.00	1.06	9.64	30.30	33.75	20.34	4.91	41.00	59.00	4.11	2.58
153-154	0.00	0.00	0.81	8.25	29.84	35.08	21.18	4.84	38.90	61.10	3.93	2.41
154-155	0.00	0.00	1.05	10.01	30.87	33.69	19.81	4.57	41.93	58.07	4.17	2.61
155-156	0.00	0.00	1.66	11.87	31.58	32.33	18.45	4.11	45.11	54.89	4.49	2.83
156-157	0.00	0.32	2.62	14.14	31.35	30.53	17.22	3.82	48.43	51.57	4.99	3.18
157-158	0.00	0.15	2.24	11.97	30.79	31.78	18.68	4.39	45.15	54.85	4.64	2.93
									Mean **41** St.Dev. **4.36**	Mean **59** St.Dev. **4.36**	Mean **4.15** St.Dev. **0.36**	

Table 4. Duplicate analyses of texture for Lake Winnipeg 99-900 core 3

Sample No	Size Fraction (μm) (Reported as percentage of <2000μm)																% Silt - % Clay			
	44-63		31-44		16-31		8-16		4-8		2-4		1-2		< 1		% Silt		% Clay	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Core-3-5-6cm	0.00	0.00	1.43	1.54	6.92	5.95	14.96	10.95	24.68	19.70	27.77	30.07	17.89	21.68	6.35	10.11	47.99	38.14	52.01	61.86
Core-3-15-16cm	0.00	0.00	1.35	0.93	4.94	3.78	11.53	8.89	26.44	23.21	30.32	32.31	19.00	22.19	6.42	8.69	44.26	36.81	55.74	63.19
Core-3-25-26cm	0.00	0.00	0.70	0.67	2.79	2.62	8.65	7.70	25.74	24.25	33.31	33.65	21.89	23.10	6.92	8.01	37.88	35.24	62.12	64.76
Core-3-35-36cm	0.00	0.00	0.46	0.40	2.23	2.08	8.28	7.59	25.69	24.45	33.63	33.88	22.65	23.49	7.06	8.11	36.66	34.52	63.34	65.48
Core-3-45-46cm	0.00	0.00	0.40	0.46	2.41	2.41	9.49	8.79	27.37	26.17	33.28	33.36	20.97	21.87	6.08	6.94	39.67	37.83	60.33	62.17
Core-3-55-56cm	0.00	0.00	0.32	0.52	2.48	2.91	10.97	10.47	29.16	28.22	33.56	33.45	19.32	19.93	4.19	4.50	42.93	42.12	57.07	57.88
Core-3-65-66cm	0.00	0.00	0.00	0.39	1.65	2.30	9.85	9.13	28.56	27.02	33.58	33.44	20.98	21.61	5.38	6.11	40.06	38.84	59.94	61.16
Core-3-75-76cm	0.00	0.00	0.00	0.38	1.42	1.97	8.44	7.83	27.73	26.29	34.41	34.34	21.81	22.32	6.19	6.87	37.59	36.47	62.41	63.53
Core-3-85-86cm	0.00	0.00	0.32	0.32	1.76	1.68	7.83	7.30	26.88	26.05	34.39	34.49	22.38	23.07	6.44	7.09	36.79	35.35	63.21	64.65
Core-3-95-96cm	0.00	0.00	0.00	0.00	0.82	0.73	6.42	5.69	25.24	24.04	35.06	35.38	24.51	25.31	7.95	8.85	32.48	30.46	67.52	69.54
Core-3-105-106cm	0.00	0.00	0.33	0.00	1.62	1.16	6.86	6.10	25.80	24.63	34.82	35.09	23.22	24.34	7.35	8.68	34.61	31.89	65.39	68.11
Core-3-115-116cm	0.00	0.00	0.00	0.36	1.36	1.99	6.52	6.75	23.24	23.36	34.53	34.25	25.04	24.58	9.31	8.71	31.12	32.46	68.88	67.54
Core-3-125-126cm	0.00	0.00	0.00	0.00	0.85	0.84	6.52	6.31	24.89	24.53	34.59	34.57	24.42	24.79	8.73	8.96	32.26	31.68	67.74	68.32
Core-3-135-136cm	0.00	0.00	0.00	0.00	0.42	0.40	6.13	5.83	26.32	25.91	36.57	36.62	23.96	24.40	6.60	6.84	32.87	32.14	67.13	67.86
RSD (%)	n/a		n/a		16.66		12.00		5.21		1.75		4.71		13.49		7.09		4.07	
Precision (%)	n/a		n/a		33.32		24.00		10.41		3.50		9.41		26.97		14.18		8.14	

Table 5. Duplicate analyses of texture for Lake Winnipeg 99-900 core 4

Sample No	Size Fraction (μm) (Reported as percentage of <2000μm)																% Silt - % Clay			
	44-63		31-44		16-31		8-16		4-8		2-4		1-2		< 1		% Silt		% Clay	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Core-4-1-2cm	0.00	0.00	1.81	1.81	7.28	7.57	16.20	14.73	26.56	24.50	28.64	29.04	15.48	16.83	4.03	5.52	51.85	48.61	48.15	51.39
Core-4-41-42cm	0.00	0.00	0.32	0.00	1.80	0.89	8.88	7.27	29.68	27.99	34.47	36.16	20.42	22.09	4.43	5.60	40.68	36.15	59.32	63.85
Core-4-71-72cm	0.00	0.00	0.75	0.00	2.79	0.89	9.05	7.89	29.15	29.37	34.46	35.66	19.56	21.33	4.24	4.86	41.74	38.15	58.26	61.85
Core-4-111-112cm	0.00	0.00	0.00	0.00	0.42	0.36	6.40	5.92	27.38	26.75	36.30	36.24	23.15	23.79	6.35	6.94	34.20	33.03	65.80	66.97
Core-4-151-152cm	0.00	0.00	0.00	0.00	0.43	0.59	7.19	6.87	28.97	27.75	36.50	35.75	21.95	22.63	4.96	6.41	36.59	35.21	63.41	64.79
RSD (%)	n/a		n/a		29.31		8.87		3.42		2.06		4.48		15.03		5.48		3.60	
Precision (%)	n/a		n/a		58.61		17.74		6.84		4.13		8.96		30.05		10.96		7.19	

Table 6. Duplicate analyses of texture for Lake Winnipeg 99-900 core 8

Sample No	Size Fraction (μm) (Reported as percentage of <2000μm)																% Silt - % Clay			
	44-63		31-44		16-31		8-16		4-8		2-4		1-2		< 1		% Silt		% Clay	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Core-8-8-9cm	0.00	0.00	0.45	0.65	2.39	2.73	7.65	7.21	22.74	21.87	34.47	34.37	23.54	23.86	8.76	9.31	33.23	32.46	66.77	67.54
Core-8-17-18cm	0.00	0.00	0.59	0.62	3.04	3.06	10.44	10.04	28.61	27.71	32.52	32.30	19.27	19.80	5.53	6.47	42.68	41.43	57.32	58.57
Core-8-26-27cm	0.00	0.00	0.00	0.00	0.33	0.00	5.85	5.50	27.86	27.17	36.47	37.12	23.70	23.76	5.79	6.45	34.04	32.67	65.96	67.33
Core-8-35-36cm	0.00	0.00	0.00	0.00	0.49	1.01	9.39	9.24	30.75	30.10	34.31	33.95	20.40	20.45	4.66	5.25	40.63	40.35	59.37	59.65
Core-8-44-45cm	0.00	0.00	0.00	0.00	0.84	0.87	9.18	9.12	32.04	31.68	34.67	34.72	19.26	19.46	4.01	4.15	42.06	41.67	57.94	58.33
Core-8-53-54cm	0.00	0.00	0.00	0.00	0.38	0.81	7.78	7.84	30.22	29.32	36.03	35.56	21.06	21.21	4.53	5.26	38.38	37.97	61.62	62.03
Core-8-62-63cm	0.00	0.00	0.00	0.00	0.73	0.00	6.61	5.90	29.81	29.76	37.24	37.83	21.20	21.86	4.41	4.65	37.15	35.66	62.85	64.34
Core-8-71-72cm	0.00	0.00	0.00	0.00	1.53	1.41	11.05	10.88	32.98	32.46	33.12	33.05	17.96	18.30	3.36	3.90	45.56	44.75	54.44	55.25
Core-8-80-81cm	0.00	0.00	0.00	0.00	0.92	0.90	9.94	9.84	33.70	33.15	34.39	34.39	17.92	18.31	3.13	3.41	44.56	43.89	55.44	56.11
Core-8-89-90cm	0.00	0.00	0.00	0.00	0.44	0.42	8.07	7.83	31.85	31.41	35.83	35.75	19.76	20.22	4.05	4.37	40.36	39.66	59.64	60.34
Core-8-98-99cm	0.00	0.00	0.37	0.00	2.30	1.21	14.54	14.43	38.38	38.78	29.71	30.49	12.93	13.27	1.77	1.82	55.59	54.42	44.41	45.58
Core-8-107-108cm	0.00	0.00	0.00	0.00	0.35	0.36	7.26	7.29	31.10	30.63	36.55	36.54	20.64	20.82	4.10	4.36	38.71	38.28	61.29	61.72
Core-8-116-117cm	0.00	0.00	0.00	0.00	0.76	0.76	7.76	7.66	29.46	28.87	35.54	35.60	21.66	21.68	4.82	5.43	37.98	37.29	62.02	62.71
Core-8-125-126cm	0.00	0.00	0.00	0.00	0.43	0.43	7.94	7.95	30.31	30.00	35.41	35.12	21.11	21.20	4.80	5.30	38.68	38.38	61.32	61.62
Core-8-134-135cm	0.00	0.00	0.00	0.00	1.55	1.52	11.27	11.12	32.31	31.89	32.62	32.74	18.31	18.55	3.94	4.18	45.13	44.53	54.87	55.47
Core-8-143-144cm	0.00	0.00	0.00	0.00	1.60	1.63	12.13	11.56	31.35	30.84	32.29	32.49	18.57	19.06	4.06	4.42	45.08	44.03	54.92	55.97
RSD (%)	n/a		n/a		25.00		2.37		1.35		0.71		1.19		7.46		1.49		1.03	
Precision (%)	n/a		n/a		49.99		4.74		2.69		1.43		2.39		14.91		2.98		2.06	

Table 7. Results for analysis of lab standard (chittick) analyzed with Lake Winnipeg 99-900 core 3

Sample No	Size Fraction (μm) (Reported as percentage of <2000μm)								% Silt - % Clay	
	44-63	**31-44**	**16-31**	**8-16**	**4-8**	**2-4**	**1-2**	**< 1**	**% Silt**	**% Clay**
chittick	20.42	23.85	30.58	15.57	6.35	2.49	0.74	0.00	96.77	3.23
chittick	20.67	24.21	30.76	15.47	6.17	2.35	0.36	0.00	97.28	2.72
chittick	20.74	24.12	30.40	15.48	6.36	2.50	0.39	0.00	97.11	2.89
chittick	20.19	23.84	30.24	15.56	6.65	2.73	0.79	0.00	96.48	3.52
chittick	20.51	24.03	30.21	15.45	6.47	2.60	0.73	0.00	96.68	3.32
chittick	20.31	24.02	30.22	15.53	6.56	2.62	0.74	0.00	96.64	3.36
chittick	20.27	23.89	30.22	15.48	6.61	2.73	0.80	0.00	96.47	3.53
chittick	20.74	24.00	30.17	15.45	6.49	2.59	0.56	0.00	96.85	3.15
chittick	20.36	23.81	30.39	15.47	6.56	2.64	0.76	0.00	96.60	3.40
chittick	20.57	23.99	30.11	15.43	6.52	2.64	0.75	0.00	96.61	3.39
chittick	20.29	23.79	30.17	15.56	6.65	2.73	0.80	0.00	96.47	3.53
Mean	20.46	23.96	30.32	15.50	6.49	2.60	0.68	0.00	96.72	3.28
St. Dev.	0.20	0.13	0.20	0.05	0.15	0.12	0.16	0.00	0.27	0.27

Table 8. Results for analysis of lab standard (chittick) analyzed with Lake Winnipeg 99-900 core 4

Sample No	Size Fraction (μm) (Reported as percentage of <2000μm)								% Silt - % Clay	
	44-63	**31-44**	**16-31**	**8-16**	**4-8**	**2-4**	**1-2**	**< 1**	**% Silt**	**% Clay**
chittick	20.78	24.45	30.54	15.72	6.26	2.26	0.00	0.00	97.74	2.26
chittick	20.76	24.21	30.55	15.44	6.28	2.40	0.37	0.00	97.24	2.76
chittick	21.33	24.50	30.87	15.46	5.89	1.95	0.00	0.00	98.05	1.95
chittick	20.68	24.09	30.75	15.43	6.25	2.43	0.37	0.00	97.21	2.79
chittick	20.89	24.19	30.58	15.46	6.21	2.33	0.34	0.00	97.33	2.67
chittick	20.80	24.28	30.59	15.44	6.18	2.36	0.36	0.00	97.29	2.71
chittick	21.29	24.27	30.73	15.41	6.10	2.20	0.00	0.00	97.80	2.20
chittick	20.97	24.46	30.48	15.44	6.03	2.27	0.34	0.00	97.38	2.62
chittick	20.83	24.35	30.57	15.41	6.15	2.34	0.35	0.00	97.31	2.69
chittick	20.76	24.21	30.69	15.35	6.24	2.38	0.37	0.00	97.26	2.74
chittick	21.12	24.30	30.75	15.47	6.12	2.23	0.00	0.00	97.77	2.23
chittick	20.68	24.33	30.64	15.44	6.18	2.36	0.36	0.00	97.27	2.73
Mean	20.91	24.30	30.65	15.46	6.16	2.29	0.24	0.00	97.47	2.53
St. Dev.	0.22	0.12	0.11	0.09	0.11	0.13	0.18	0.00	0.29	0.29

Table 9. Results for analysis of lab standard (chittick) analyzed with Lake Winnipeg 99-900 core 8

	Size Fraction (μm) (Reported as percentage of <2000μm)								% Silt - % Clay	
Sample No	**44-63**	**31-44**	**16-31**	**8-16**	**4-8**	**2-4**	**1-2**	**< 1**	**% Silt**	**% Clay**
chittick	20.365	23.947	30.171	15.467	6.567	2.687	0.796	0.000	96.52	3.48
chittick	20.805	24.154	30.334	15.443	6.401	2.487	0.376	0.000	97.14	2.86
chittick	20.409	23.958	30.415	15.511	6.379	2.565	0.763	0.000	96.67	3.33
chittick	21.454	24.885	30.358	15.500	5.783	2.020	0.000	0.000	97.98	2.02
chittick	20.406	23.995	30.057	15.404	6.592	2.750	0.795	0.000	96.46	3.54
chittick	20.399	23.892	30.174	15.462	6.590	2.711	0.771	0.000	96.52	3.48
chittick	20.352	23.900	30.268	15.366	6.611	2.730	0.774	0.000	96.50	3.50
chittick	20.399	23.782	30.229	15.440	6.667	2.711	0.771	0.000	96.52	3.48
chittick	20.318	23.909	30.107	15.391	6.651	2.806	0.818	0.000	96.38	3.62
chittick	20.666	23.800	30.277	15.359	6.532	2.626	0.739	0.000	96.63	3.37
chittick	20.323	23.892	30.202	15.416	6.631	2.741	0.796	0.000	96.46	3.54
chittick	20.881	24.236	30.659	15.473	6.114	2.296	0.342	0.000	97.36	2.64
chittick	20.732	24.191	30.467	15.571	6.266	2.398	0.376	0.000	97.23	2.77
chittick	20.735	24.032	30.549	15.468	6.362	2.467	0.387	0.000	97.15	2.85
chittick	20.633	24.140	30.789	15.466	6.195	2.401	0.376	0.000	97.22	2.78
chittick	20.496	24.081	30.567	15.626	6.352	2.490	0.387	0.000	97.12	2.88
chittick	20.967	24.191	30.750	15.425	6.073	2.263	0.331	0.000	97.41	2.59
Mean	20.61	24.06	30.37	15.46	6.40	2.54	0.56	0.00	96.90	3.10
St. Dev.	0.30	0.25	0.22	0.07	0.25	0.21	0.25	0.00	0.46	0.46

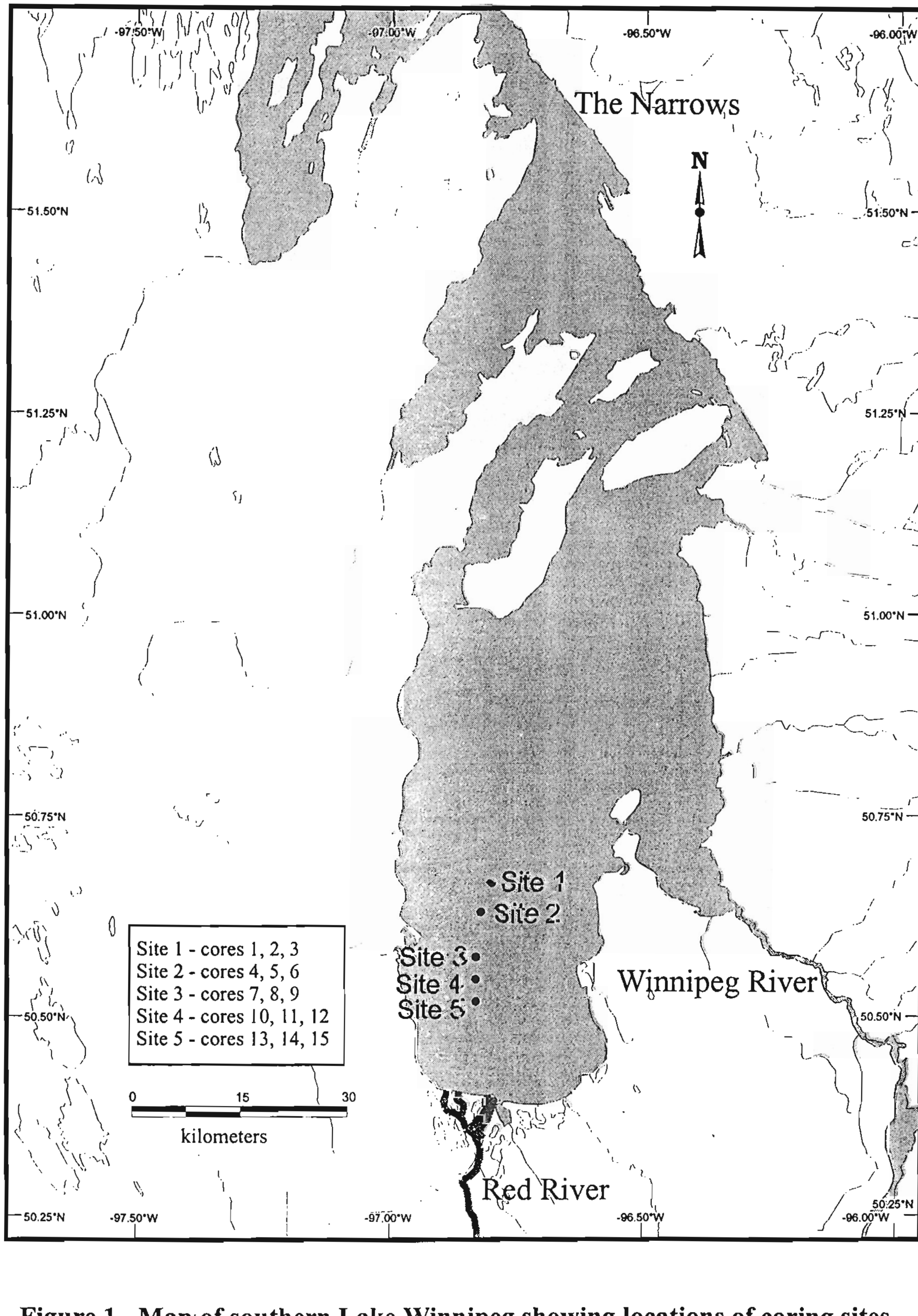

Figure 1. Map of southern Lake Winnipeg showing locations of coring sites

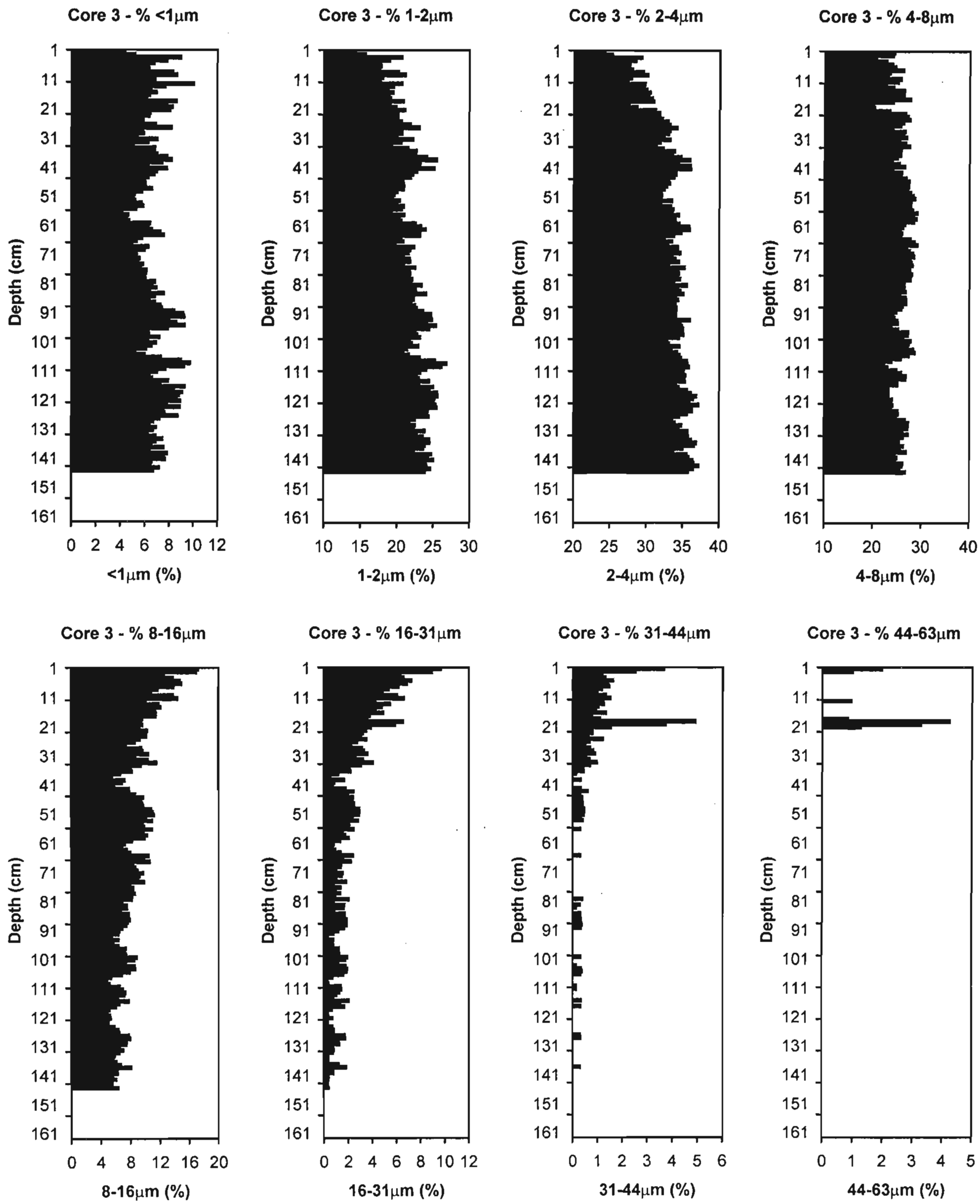

Figure 2. Down-core variations in detailed grain-size classes for Lake Winnipeg 99-900 core 3

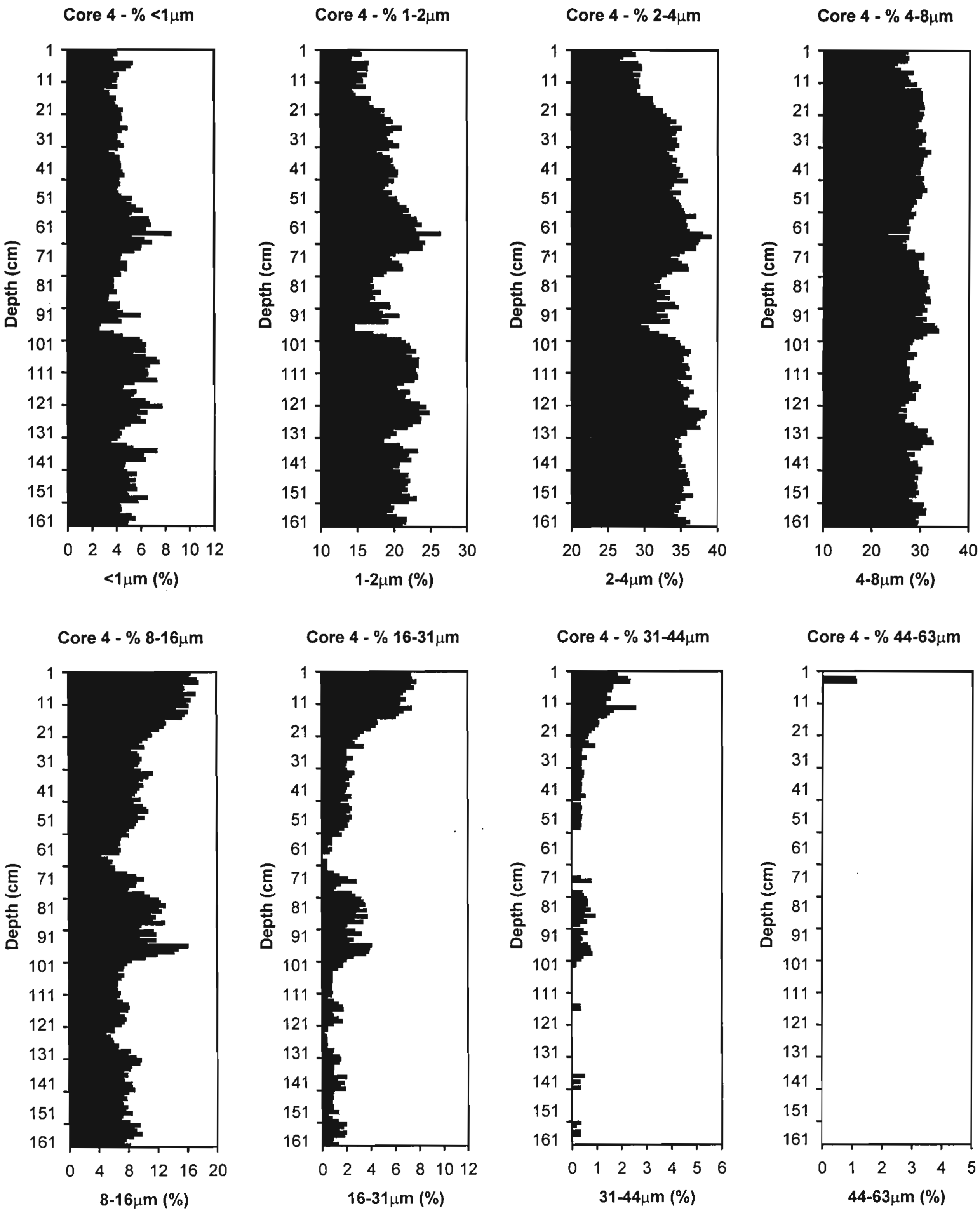

Figure 3. Down-core variations in detailed grain-size classes for Lake Winnipeg 99-900 core 4

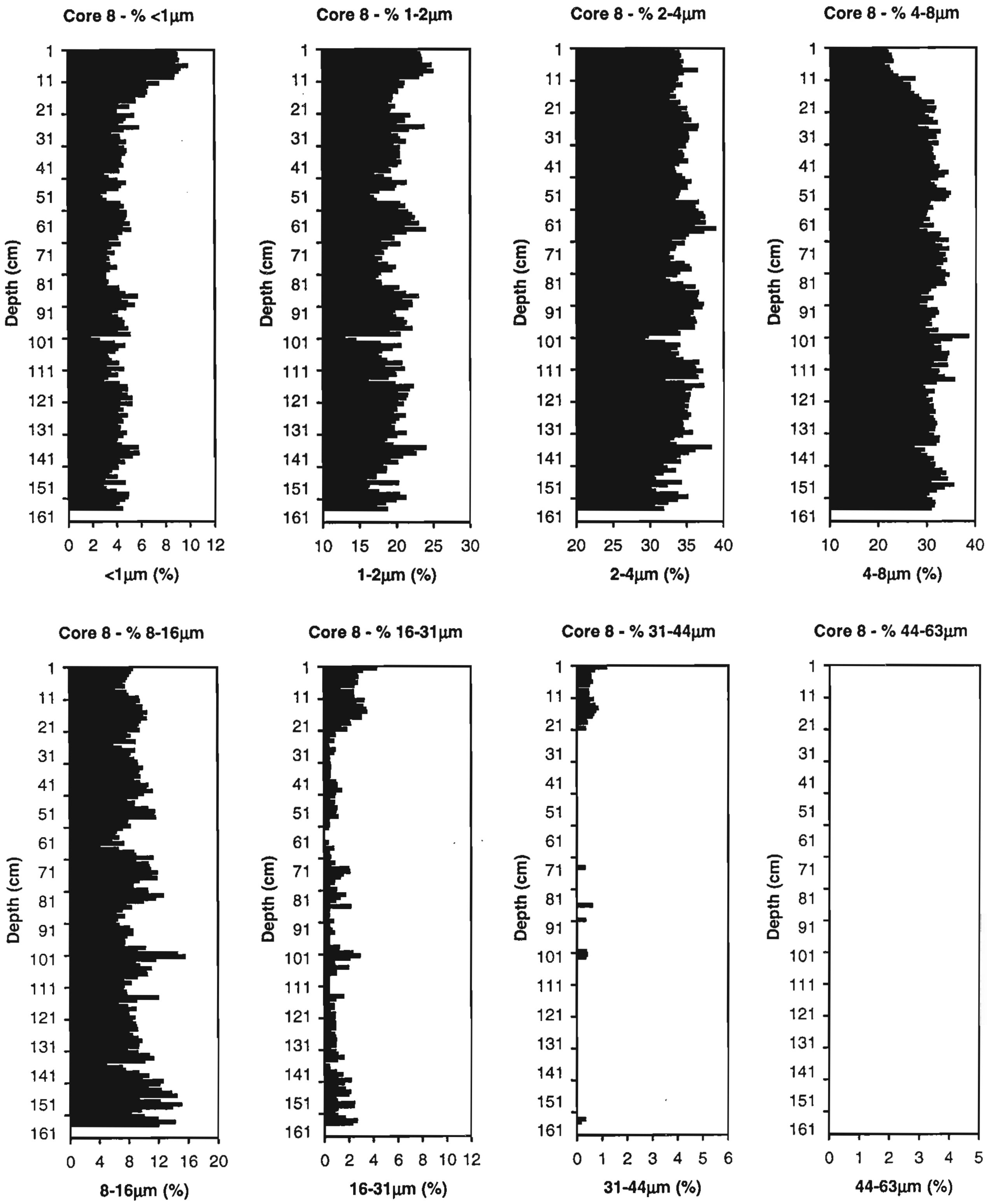

Figure 4. Down-core variations in detailed grain-size classes for Lake Winnipeg 99-900 core 8

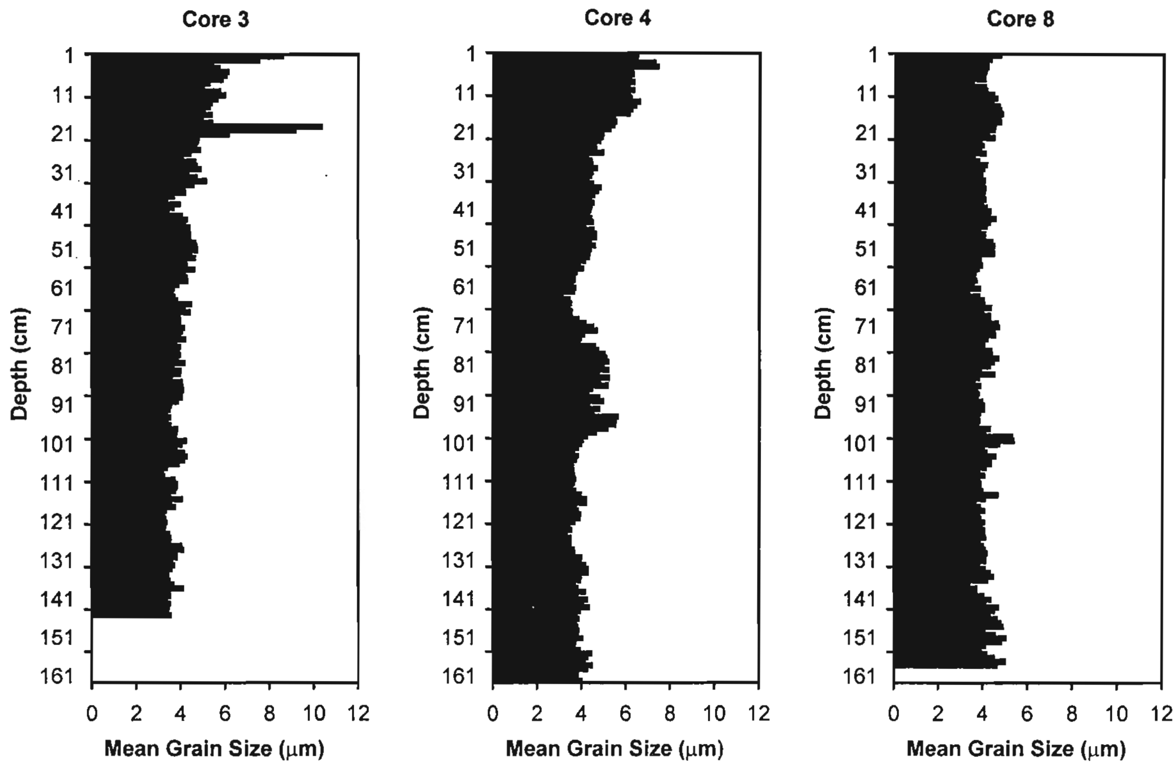

Figure 5. Down-core variations in mean grain size for Lake Winnipeg 99-900 cores 3, 4 and 8

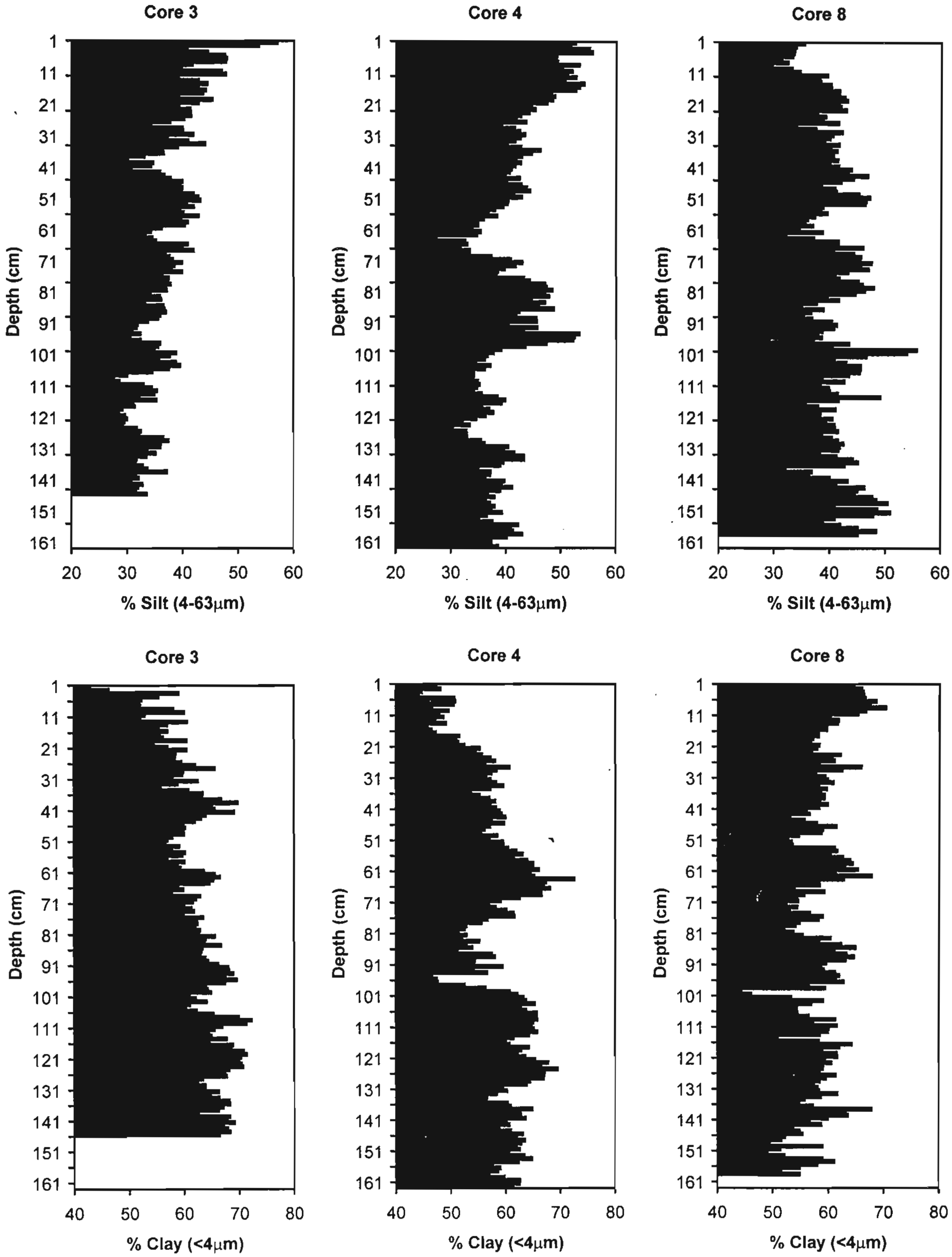

Figure 6. Down-core variations in % silt and % clay for Lake Winnipeg 99-900 cores 3, 4 and 8

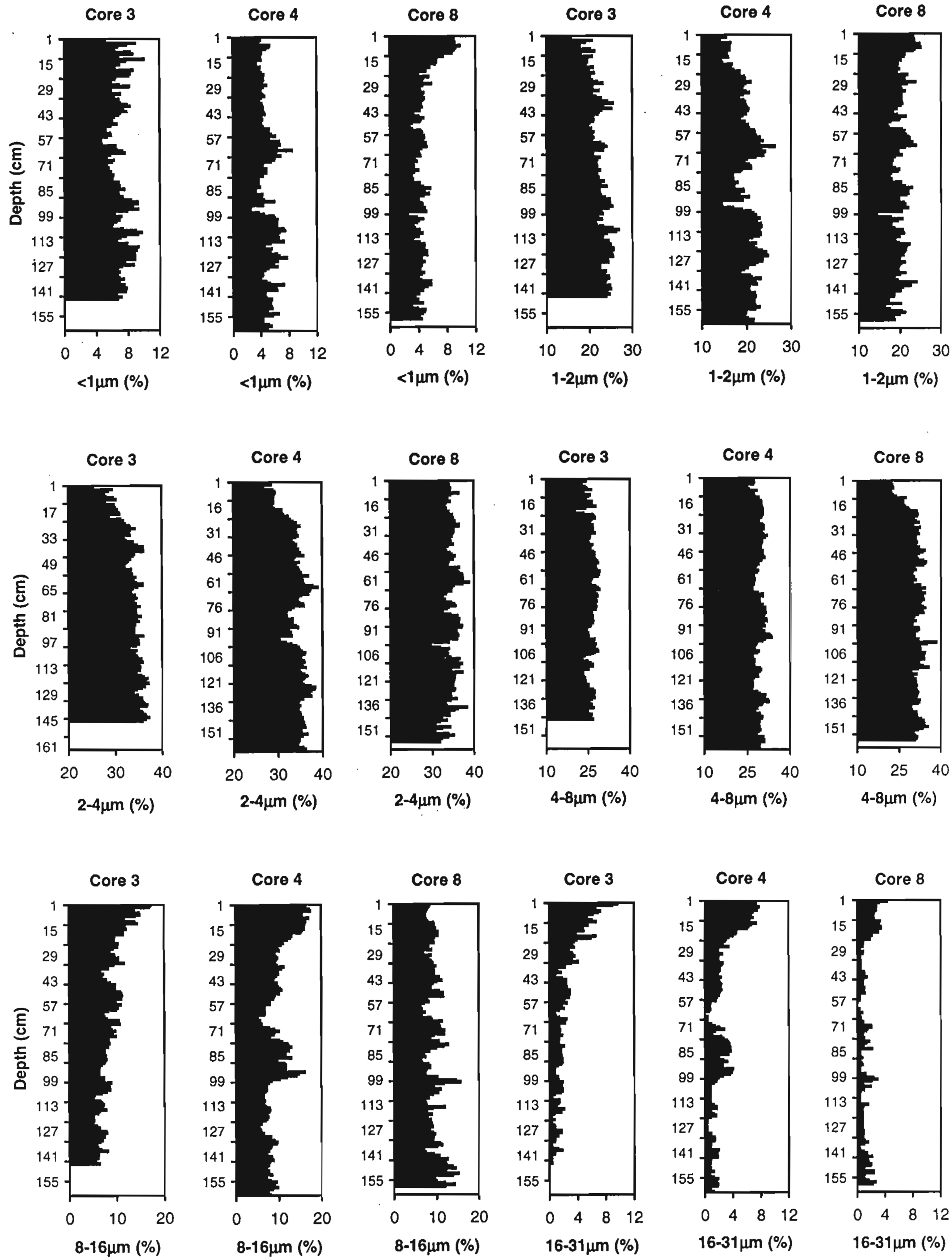

Figure 7. Single grain size classes and unique combinations of adjacent grain-size classes for Lake Winnipeg 99-900 cores 3, 4 and 8.

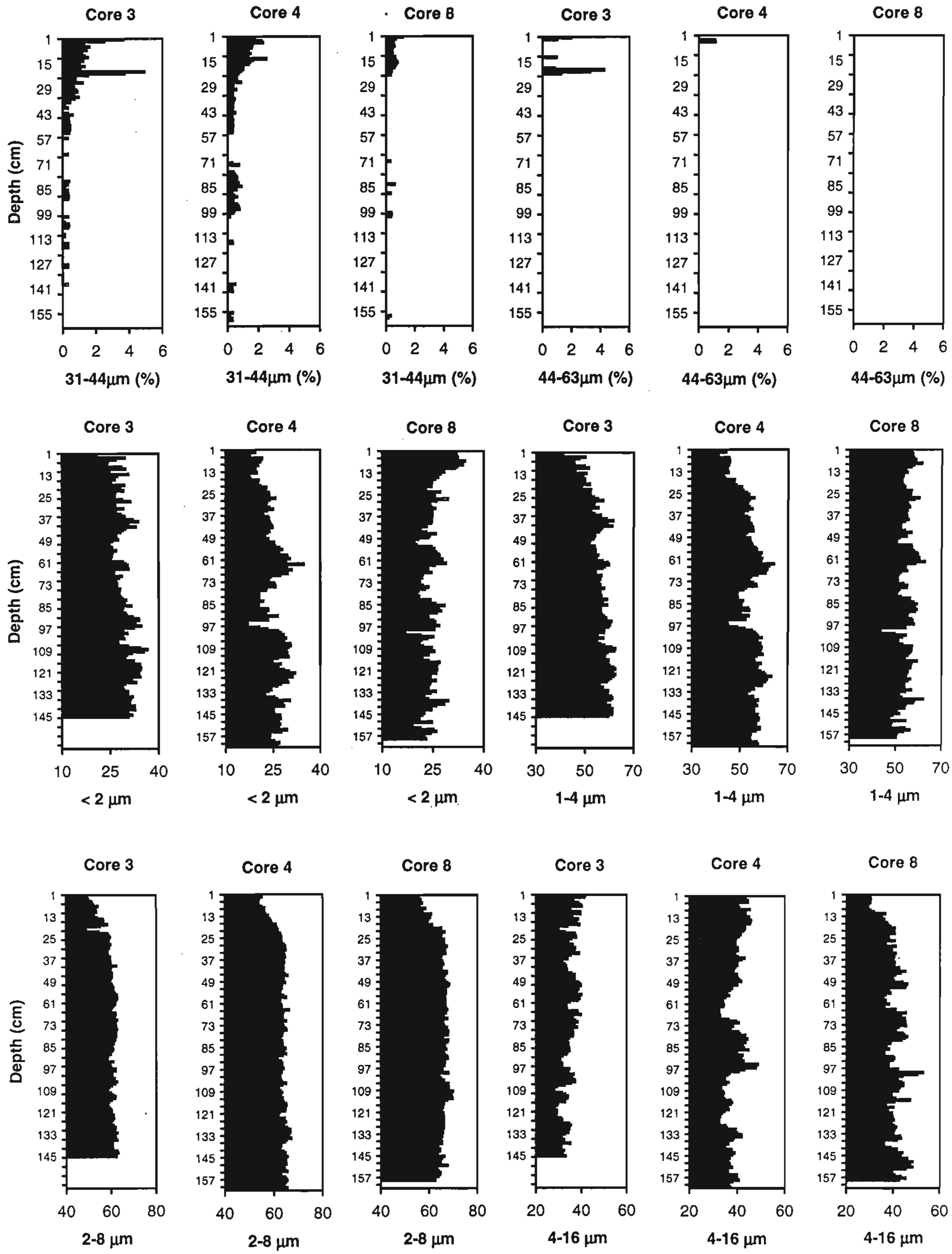

Figure 7 continued

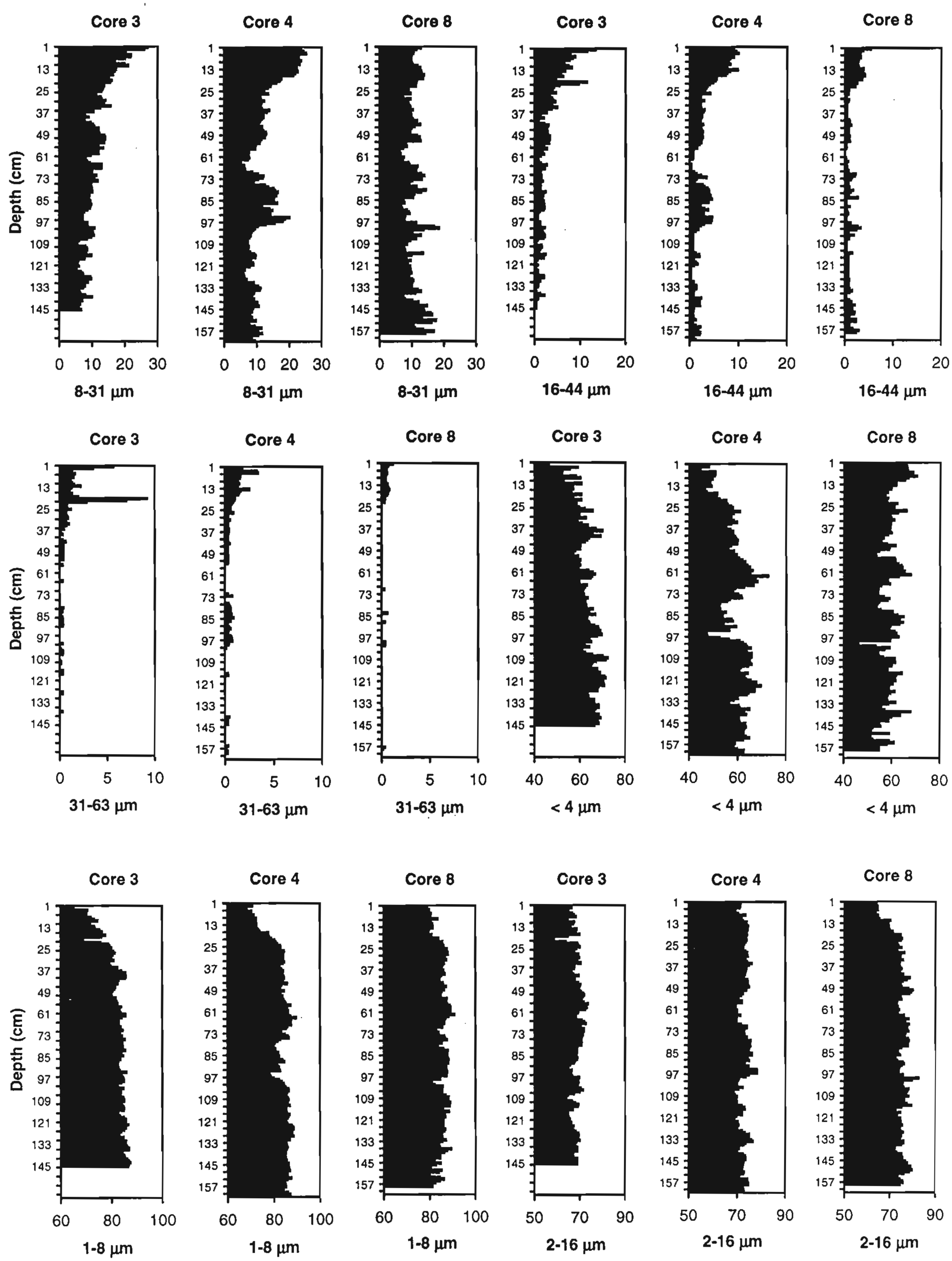

Figure 7 continued

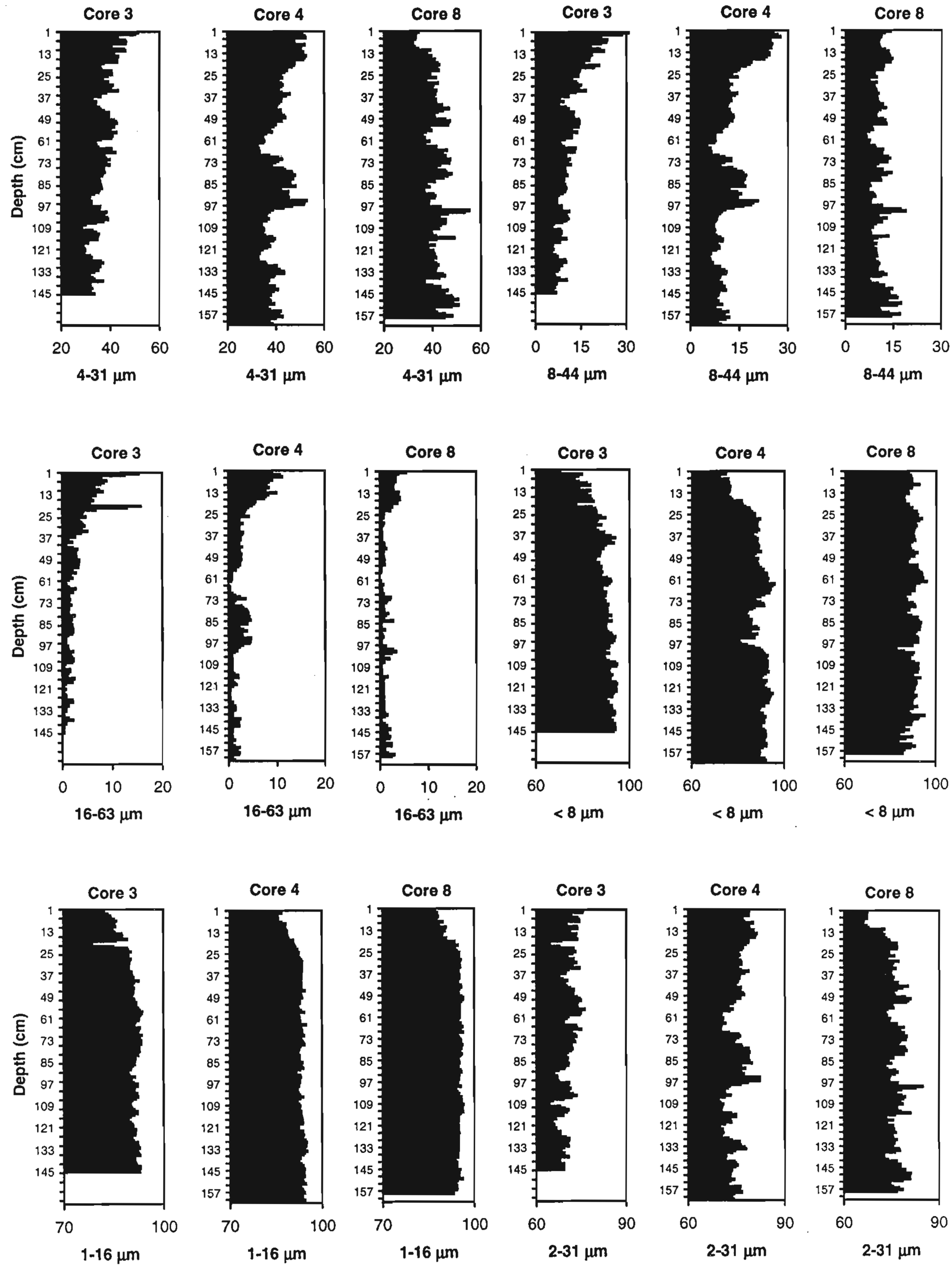

Figure 7 continued

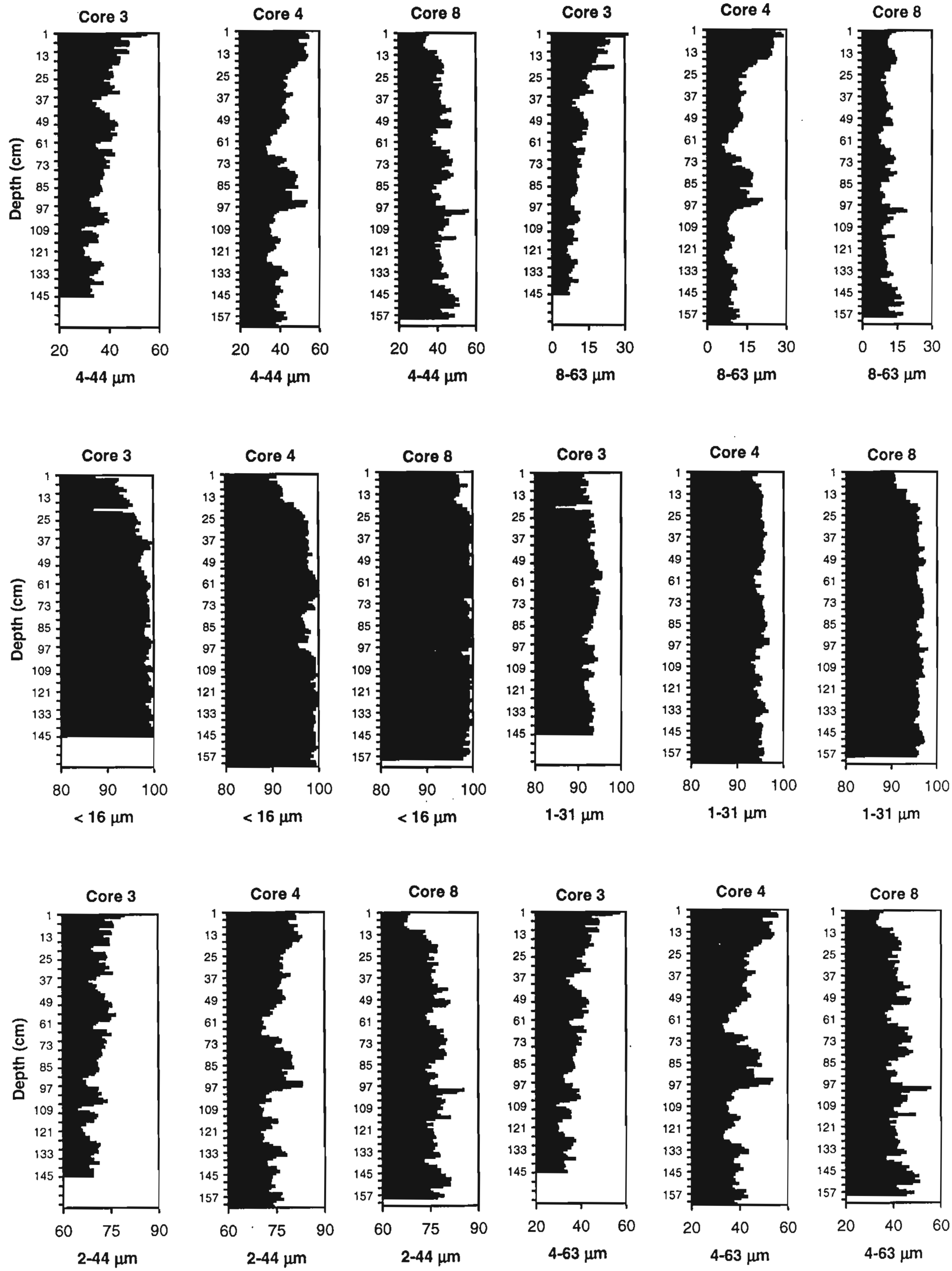

Figure 7 continued

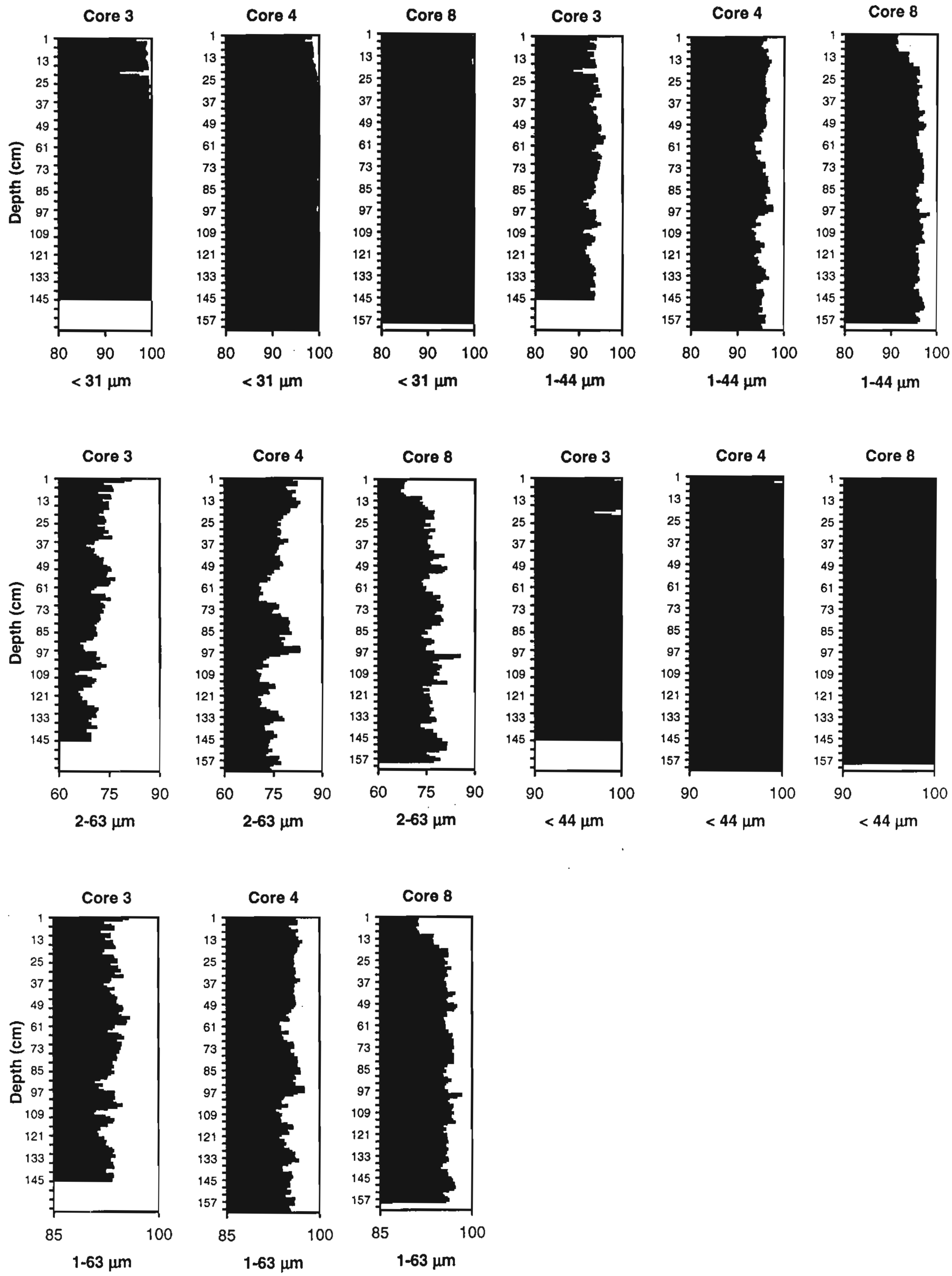

Figure 7 continued

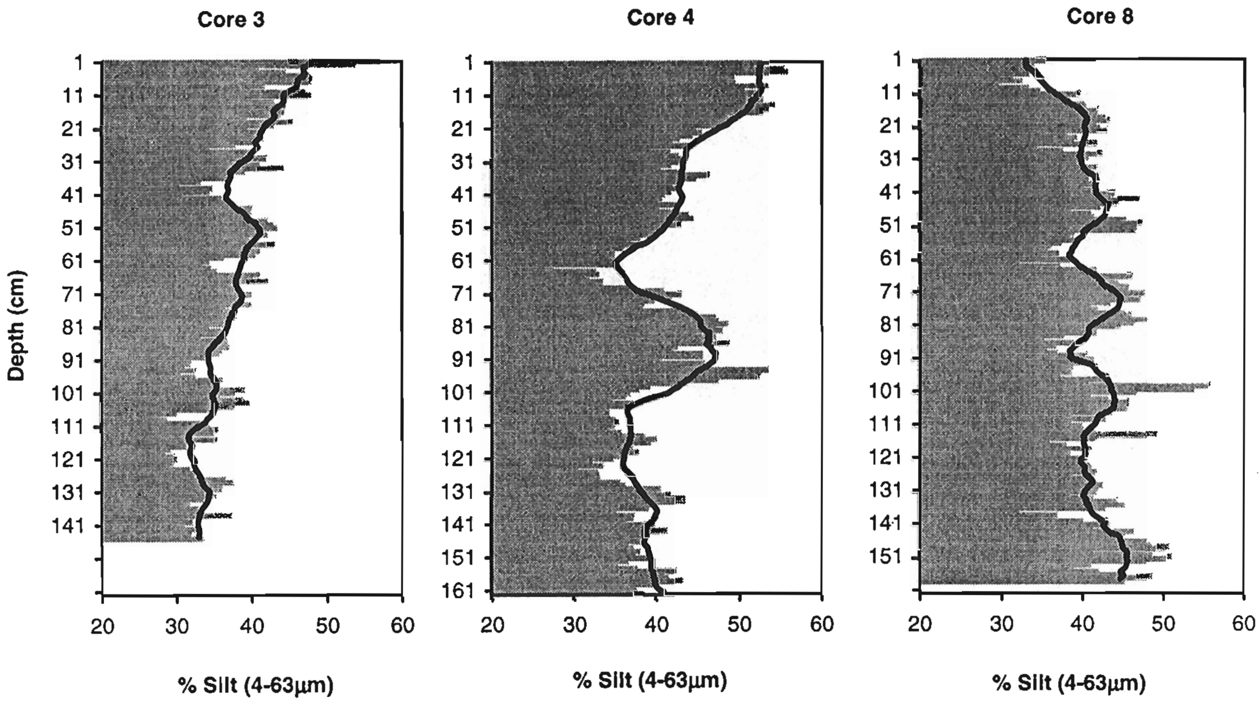

Figure 8. 15-point moving mean of grain size data (black) superimposed on silt content (grey) for cores 3, 4 and 8. The moving mean defines dm-scale shifts in silt content.

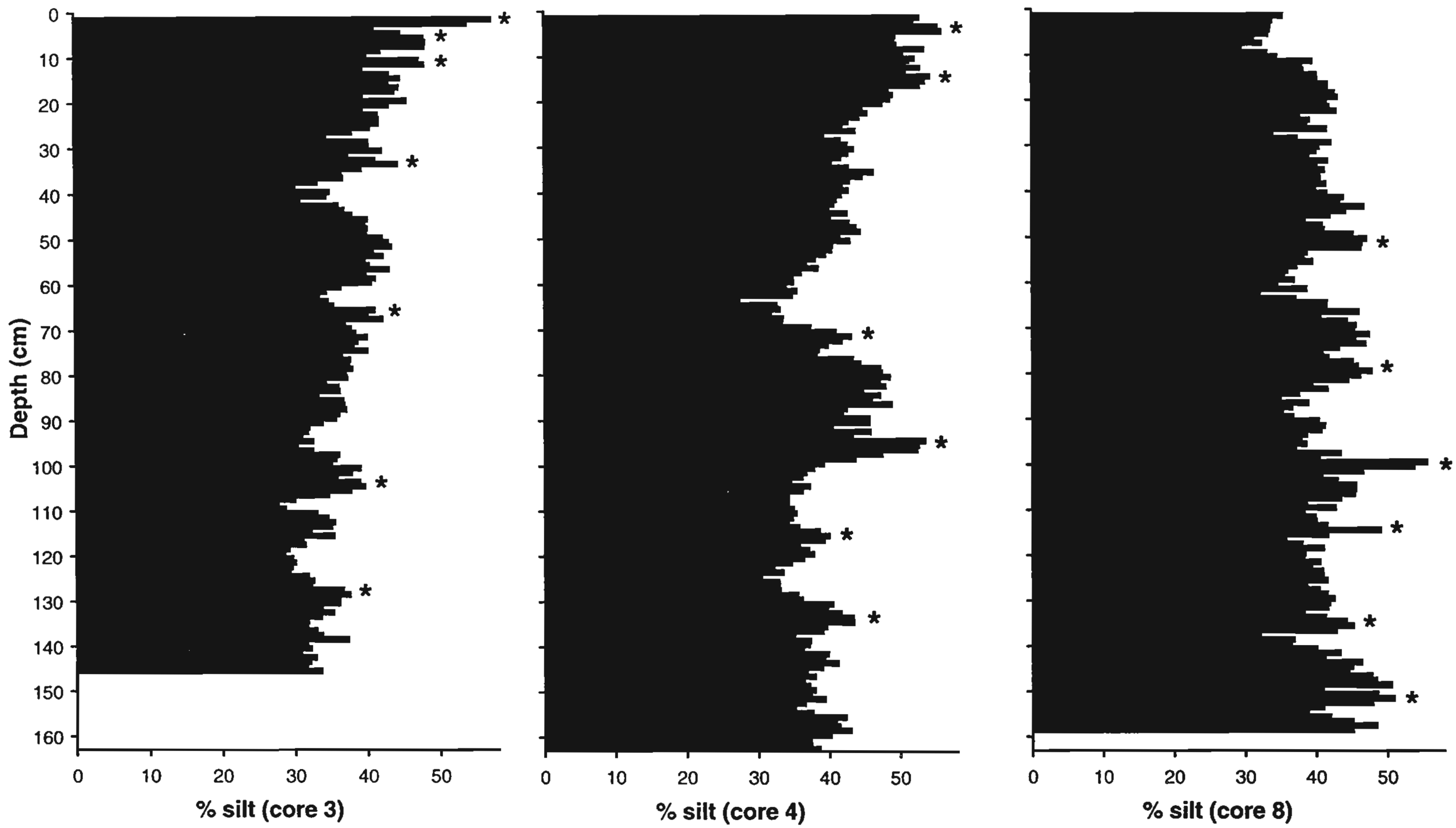

Figure 9. Down-core variations in % silt for cores 3, 4 and 8. The asterisks indicate readily apparent layers of higher silt content than background.

5.2 Elemental analysis of Lake Winnipeg 99-900 cores 3, 4 and 8

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ABSTRACT

Following the 1997 Red River flood, research addressing the history and controls on the flood hazard included analysis of sediments in Lake Winnipeg to assess flood history and drainage basin evolution. To do so, 15 cores, each about 1.5 m long, were collected from the south basin during a cruise of the Canadian Coast Guard Ship (CCGS) Namao in August 1999, designated Geological Survey of Canada (GSC) cruise 99-900. Elemental analysis of three cores was used to provide a record of compositional variations and test for the presence of trends and/or events in offshore sedimentation. The cored sediments were attributed approximately to the past 1100 years on the basis of radiochemistry, paleomagnetic analysis, palynology and radiocarbon dating. Many of the 41 elements analyzed show monotonous records. Ca, Mg and Cd, however, show decimeter-scale variations throughout the record, some of which are correlatable. Ca and Mg show a strong positive correlation with one another in all three cores. Variations in Cd correlate with the abrupt shifts in silt content in core 4, but do not correlate with silt in the other two cores. Increases in the concentrations of some trace metals, including Ag, Cd, Cu, Hg, Pb, Sb, U and Zn, as well as P, occur in the top 25 cm of the cores, in some cases may be of sufficient magnitude to be attributable to anthropogenic inputs. In several cases concentrations level off or decrease in the top 10 cm, and could imply recent reductions in inputs. Trends in the upper portion of the cores that are correlatable from core to core are also a useful confirmation of core integrity.

INTRODUCTION

The Red River flood of 1997 was a major disaster that drove 103,000 people from their homes. Much is being done, however, to reduce comparable damage and disruption in the future through enhanced dikes and diversions, as well as revised land use and water management practices. The design of these works requires an optimal understanding of the risk. Research therefore has addressed the nature of the largest known flood, in 1826, whether comparable large floods have occurred in recent centuries, and how geomorphic, climatic, land use, and tectonic factors may be changing the flood hazard. These issues are being addressed by examining the geomorphic processes governing evolution of the Red River, archival records of flood history, floodplain stratigraphic records, tree-ring records, changes in valley gradients, and by examining the stratigraphy of Lake Winnipeg sediments (Thorleifson et al., 1998). The coring in Lake Winnipeg, receiving basin of waters from the Red River, was designed to sample sites most likely to have recorded any influx of sediments from the Red River that may have occurred. In addition to recording gradual changes in Red River sediment transport, it was thought that flood events might be recognizable, due to unique properties allowing differentiation from other sediments in the lake, although it was unclear what attribute would best distinguish flood-related sediments. The cores therefore were thoroughly analyzed for chronology, as well as for a broad range of physical, chemical and biological properties to determine which, if any, would record a history of flooding.

Variations in element concentrations in sediments can arise from paleoenvironmental changes, including climate change, shifts in source areas, and anthropogenic effects. Previous elemental analysis of long cores and bottom sediment samples from the north and south basins of Lake Winnipeg revealed information on the shifting provenance of the lake sediments (Henderson and Last, 1998). It was thought that elemental analysis might also provide a record of floods, as floodwaters could transport distinctive material. However, elemental analysis of sediments in three small lakes in the Red River Valley did not indicate a flood record for the elements studied (Medioli, 2001; 2003). Increases in Hg and Pb concentrations in the top portion of sediments from Lake Winnipeg have, however, been used to show that inputs of these metals began to increase about 100 years ago, and have leveled off over the past 20-30 years (Lockhart, 1996; Lockhart et al., 2000).

It therefore was thought that elemental analysis of the offshore sediments would provide an insight into compositional variations in the sediment supply to the basin, possibly including floods.

LAKE WINNIPEG

Lake Winnipeg, located in central North America, is the eleventh largest lake in the world, having an area of 24,000 km² (Hutchinson, 1975). The lake straddles the contact between Paleozoic carbonate rocks to the west and Precambrian igneous and metamorphic rocks of the Canadian Shield to the east. A smaller south basin, approximately 90 km by 40 km, is separated from a north basin, approximately 240 km by 100 km, by a narrow passage known as The Narrows. The glacially-scoured

* Italicized text is repeated in each chapter

depression in the rocks underlying the lake, with a depth of 50-100 m, is largely filled with fine-grained glacial Lake Agassiz sediments, overlain by up to 15 m of post-glacial Lake Winnipeg sediments (Todd and Lewis, 1996). The bathymetry of the lake is shallow and the bottom is flat, with depths averaging 9 m in the south basin and 16 m in the north basin. The lake has a catchment area extending from the Rocky Mountains to very near Lake Superior, including the basins of the Winnipeg, Saskatchewan, Red, Dauphin and numerous smaller rivers. Outflow from the lake is north to Hudson Bay, through the Nelson River. Post-glacial uplift has caused the north end of the basin to rise relative to the south, causing a gradual rise of lake levels that continues at present (Lewis et al., 2000). The mean annual temperature of the region, recorded at Gimli, is +1.4°C, although the continental climate of the region ranges from hot summers to very cold winters. The mean annual precipitation is 50.8 cm. The lake is ice free from early May to late November (Ice Thickness Climatology, 1992) and ice cover from November to May is consistently thick and continuous. The lake waters are poorly stratified to unstratified and during the summer months water temperatures range from +17°C in the north basin to +19.5°C in the south basin (Todd, 1996), hence bottom sediment temperatures are equally warm in mid-summer. The lake supports a commercial fishery, it is a major destination for recreation, and lake levels are regulated to optimize hydroelectric power generation on the Nelson River.

SAMPLING AND ANALYTICAL METHODS

Selection of five sampling sites in the south basin of Lake Winnipeg was based on proximity to the Red River mouth and on the absence of ice scour on sidescan sonar records previously obtained in 1994 on the 94-900 Namao cruise (Lewis et al., this volume) (Figure 1). Site 5 was the southernmost point on the north-south survey line that lacked ice scour. Sampling was conducted in calm weather on August 24, 1999 from the CCGS Namao. Three cores were obtained at each of the five sites using a gravity corer consisting of a 100 kg weightstand over a 2 m steel pipe with a 10 cm diameter plastic liner tube. The length of the cores ranged from 107 cm to 170 cm. The cores were sealed, labelled and transported to Gimli, Manitoba on August 29, where they were refrigerated, and subsequently transported via refrigerated truck to the GSC Atlantic core storage facility in Dartmouth, N.S. A monitoring device attached to the core bundle indicated that the sediments did not exceed a temperature of 19°C at any time during transport. Paleomagnetic and physical property data, determined at the laboratory of Professor J.W. King at the University of Rhode Island, provided information used to select cores that would be representative of the offshore sediments (King et al., this volume). Paleomagnetic profiles indicated more rapid accumulation of sediments at the more northerly sites and hence a higher resolution for examining environmental change. Based on these observations, core 8 (site 3), core 4 (site 2), and core 3 (site 1) were selected as the primary records for detailed study.

At GSC Atlantic, the entire working half of the cores was sliced into 1-cm sections, packaged in vials and refrigerated. At the Freshwater Institute (FWI) in Winnipeg, a 1 cc subsample was removed for pollen and textural analysis, and the remaining material was freeze dried and pulverized. Following completion of radiochemical analyses at the FWI, samples from cores 4 and 8 were shipped to ALS Chemex in Vancouver, where a one-gram (dry weight) subsample was analyzed. Elemental analysis was performed for 41 elements on 162 samples from core 4, and 158 samples from core 8, after re-ordering. Subsequently, it was recognized that it would be very useful to have inorganic geochemical data from a third core. Therefore, core 3 was later analyzed at the Analytical Chemistry Laboratories of the Geological Survey of Canada (GSC) in Ottawa, following re-ordering. Elemental analysis was performed on 32 of the 41 elements analyzed in the other two cores, and an additional 21 elements, including several rare earth elements (REE's), were also analyzed as they were part of a standard package of elements commonly analyzed. Care was taken to ensure that the samples were prepared and analyzed using equivalent procedures, so that the results from the two laboratories would be comparable.

Methods used for core 3 are tabulated in Table 1. For core 3, the samples were subjected to near total digestion using nitric (HNO3), hydrofluoric (HF) and perchloric acids (HClO4). Of the 32 elements that were also analyzed in the other two cores, Al, Ba, Be, Ca, Cr, Co, Cu, Fe, Mg, Mn, Ni, P, K, Na, Sr, Ti, V and Zn concentrations were determined by ICP-ES (inductively coupled plasma-emission spectrometry), while Sb, Cd, Cs, Ga, Pb, Mo, Nb, Rb, Ag, Ta, Tl, Th, U and Y concentrations were determined by ICP-MS (inductively coupled plasma-mass spectrometry). Of the additional elements not analyzed in the other two cores, Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Nd, Pr, Sm, Tb, Tm, Yb, Bi, Hf, In, Sn, Te and Zr were analyzed by ICP-MS, while Sc was analyzed by ICP-ES. Two important changes were made to the normal laboratory procedure in order to ensure equivalent treatment, and hence results of the samples from the two laboratories. For both ICP-ES and ICP-MS the lithium metaborate fusion step normally used to carry out total sample dissolution was omitted. For ICP-MS, dilution of the test solution was cut in half to ensure the same level of dissolution obtained by the other laboratory.

Methods used for cores 4 and 8 are tabulated in Table 2. For cores 4 and 8, the samples were subjected to near total digestion using nitric (HNO3), hydrofluoric (HF) and perchloric acids (HClO4). Al, Ba, Ca, Cr, Cu, Fe, Mg, Mn, Mo, P, K, Na, Ti, V and Zn concentrations were determined by ICP-ES. Sb, Ce, Cs, Ga, Ge, La, Li, Nb, Rb, Ta, Te, Tl, Th, U and Y concentrations were determined by ICP-MS. Be, Bi, Cd, Co, Pb, Ni, Ag, Sr and W concentrations were determined by ICP-MS/ICP-ES. As was analyzed by AAS-Hydride/EDL (atomic absorption spectrometry-hydride generation/ electrodeless discharge lamp), following aqua regia (oxidizing mixed acid: 1 part nitric acid to 3 parts HCl) partial digestion. Hg was analyzed by CV-AAS (cold vapour-atomic absorption spectrometry), following aqua regia partial digestion.

Analytical precision and accuracy were monitored through the analysis of duplicates and the GSC laboratory standard TCA8010, respectively.

Quality assurance and quality control

Corrections were applied to remove significant analytical trends that masked natural trends in the data set. Analytical trends were indicated by the standards and were evident in data plots because the samples had been re-ordered prior to analysis. The samples were re-ordered so that analytical trends could be differentiated and removed from natural trends. Figure 2a shows Ba concentrations plotted in the order of analysis (lab #). The slope of the trendline indicates a gradual and systematic increase in values throughout analysis (increasing lab #'s). If the samples had not been re-ordered, this gradual shift might have been interpreted as a natural shift in concentration with depth. Re-arrangement of the samples into depth order causes artificial cycles to become apparent (Figure 2b). Trend removal eliminates the linear trend evident in laboratory order plots (Figure 2c) and the cycles in depth plots (Figure 2d).

Linear trends (type A) were removed by linear regression and removal of the trend while maintaining the mean value of the data set. Data sets in which subsets of the data followed separate trends (type B) were not adjusted, in the interest of preserving natural trends. Data sets exhibiting stepwise trends (type C), with three or more consecutive points significantly higher or lower than surrounding points in the analytical order, were corrected by shifting the stepped region up or down by a constant. Some data sets were unusable (type D), because of close proximity to the lower detection limit or erratic analytical trends. In addition, type D trends generally coincided with poor duplicate analyses. For data sets that were a combination of types A and C a linear correction was first applied to the affected data, followed by a type C correction. The type of trend observed for each element in cores 4 and 8 is listed in Table 3.

Detection limits for each element are listed in Table 1 for core 3 and Table 2 for cores 4 and 8. Results of duplicate analyses and analytical precision for each element are shown in Table 4 for core 3 and in Tables 5, 6, 7, 8 and 9 for cores 4 and 8. Analytical precision is expressed as RSD (relative standard deviation) and precision as defined by Garrett (1969). Comparisons of first analysis versus second analysis illustrate the degree of precision obtained (Figure 3) for cores 4 and 8. For core 3, acceptable precision (≤ 20 %) was attained for all elements excluding Ag (Table 5). For cores 4 and 8, acceptable precision was not attained for Sb, As, Ba, Be, Bi, Cd, Li, Hg, Mo, Ag, Na, Ta, Te and W (Tables 6, 7, 8 and 9). Overall, better precision was attained for core 3 than for cores 4 and 8.

Accuracy of laboratory results was monitored by analysis of the standard TCA-8010. Results for TCA-8010 (Tables 10 and 11) compared well with informational values obtained over an 8-year period. According to CANMET guidelines, 95 % of the data for a standard should fall within the 2SD (2 times the standard deviation) range for informational values (or provisional/certified values) for the standard (Steger, 1998). According to these guidelines, acceptable accuracy was not attained in core 3 for Al, Be, Cd, Ca, Cr, Fe, P, Ag, Ti and Y (Table 10), although for this small data set the standard was only analyzed five times. For cores 4 and 8, acceptable accuracy was not attained for Al, Sb, Ba, Cd, Ca, Ce, Ga, Fe, La, Mn, K, Ag, Th and Ti (Table 11). Informational values for TCA-8010 were not available for As, Hg and Te. Whereas TCA-8010 was analyzed throughout the laboratory run for core 3, this standard was analyzed only at the end of the laboratory run for cores 4 and 8. Therefore, data for the latter are of limited value in assessing accuracy. An examination of the results for the standards inserted by the commercial laboratory (for cores 4 and 8) showed that the desired level of accuracy was not attained for Sb, As, Ba, Bi, Ni and Tl. Accuracy could not be determined for Hg because the upper and lower limits for the Hg standard were not available. Overall, the level of accuracy attained was similar for cores 3, 4 and 8. The implication for elements with poor accuracy from either of the two laboratories is that a direct comparison of concentrations between cores analyzed at different laboratories should not be made. Although it is recognized that absolute values for element concentrations between laboratories will not in all cases be comparable, it is however still reasonable to assume that trends in concentration should be comparable core to core.

RESULTS

The down-core variations in element concentrations for core 3 are listed in Tables 12 and 13. The elements listed in Table 12 were also analyzed in cores 4 and 8, and are displayed graphically in Figure 4. The elements listed in Table 13 were not analyzed in the other two cores and are not presented graphically, nor are they discussed in this open file. The down-core variations in element concentrations for cores 4 and 8 are listed in Tables 14 and 15, respectively, and shown in Figure 5. Results for Sb, As, Mo, Te, and W for core 4 and As and Te for core 8 were deemed unusable (type D) and therefore not shown graphically

The majority of the elements show relatively monotonous records, whose only contrasts are non-correlatable, single-slice excursions either throughout the core or sporadic in occurrence with depth. Given the offshore location of the cores and their close proximity to each other, one would expect that large-scale influences such as climate change, sediment supply shifts, floods or anthropogenic change would affect the entire offshore environment and would cause a similar response in adjacent cores. Therefore, sporadic single-slice excursions are considered to be analytical.

Ca, Mg and Cd, however, show somewhat correlatable, decimeter-scale variations throughout the records, some of which show a correlation with silt content (Simpson and Thorleifson, this volume) in the sediments (Figure 6). Cross plots indicate the degree of correlation between pairs of these parameters (Figure 7). Ca and Mg concentrations have the highest degree of correlation, with r^2 values of 0.63, 0.69 and 0.75 for cores 3, 4 and 8, respectively. For some intervals, Ca and Mg visually correlate well with % silt, although the r^2 is less than 0.10 in all cores for both Cd vs. Ca and silt vs. Ca. Variations in Cd and silt appear to be similar in core 4, although this co-variance is not evident in cores 3 and 8 (Figure 6). Cd and silt do have a moderate degree of correlation in core 4, with an r^2 value of 0.49. An r^2 value of less than 0.2 was observed for Cd vs. silt plots for cores 3 and 8. Iron is generally monotonous, but also shows subtle decimeter-scale trends. These trends do not appear to correlate with decimeter-scale trends in Ca, Mg, Cd or silt. Correlatable inter-core spikes in Ca, Mg, and Cd occur throughout the cores and provide relative age markers (Figure 8; Table 16). Eight such markers are present in the cores, although the uppermost Mg marker occurs at virtually the same depths as the uppermost Ca marker.

Elevated concentrations of Ag, Cd, Cu, Hg, Pb, P, Sb, U and Zn are present in the upper 25 cm of the cores (Figures 4 and 5). In general, concentration increases begin around 25 cm depth, rise abruptly to 20 cm depth, and then level off or decrease. Increases in Ag concentrations occur at around 20 cm depth and level off rapidly in each core, although the increases are subtler in cores 4 and 8 than in core 3. Increases in Cd concentrations occur just below 20 cm depth, but are not distinct relative to the lower portions of the cores, which are characterized by several cycles of increases and decreases. Cu concentrations in all cores show only small increases beginning around 25 cm depth. In cores 4 and 8, Hg concentrations increase abruptly above 25 cm, remain constant to 7 cm, and decrease slightly from 7 cm to the tops of the cores. Pb concentrations in all three cores increase abruptly above 25 cm depth. For cores 4 and 8, a gradual slight decrease in concentrations is observed from 20 cm depth to the tops of the cores, whereas for core 3, concentrations continue to rise slightly or level off above this depth. P concentrations in the cores begin increasing around 20 cm depth and continue to gradually rise up-core, to about 5 cm in depth. Above this depth, concentrations level off or begin to decrease slightly. Results for Sb were poor for cores 4 and 8. In core 3, Sb concentrations rise between 20 to 15 cm depth, above which they level off. In cores 4 and 8, U concentrations increase abruptly above 20 cm depth, and decrease gradually to near background levels by the tops of the cores. In core 3, the increase in U concentration is more gradual, beginning around 25-30 cm depth, reaching peak levels by 15 cm depth, and declining somewhat above this depth. Zn concentrations in the cores show subtle increases beginning around 20-25 cm depth.

Table 17 summarizes the top-of-core concentration increases in Ag, Cd, Cu, Hg, Pb, P, Sb, U and Zn in each of the cores. Overall, Hg concentrations in cores 4 and 8 exhibit the greatest increase, rising from background levels of 40-50 ppb to a maximum of 110-120 ppb, a 2.4- to 2.7-fold increase. Increases in the concentration of Ag are also significant, especially in core 8 where the increase is 2.5-fold. Pb and P concentrations increase up to 1.5-fold. All other elements exhibit lesser increases of 1.2- to 1.4-fold.

DISCUSSION

Sediment provenance

Elemental studies of lake-bottom sediments are useful indicators of sediment provenance, and can be used to show how the relative dominance of source areas has changed throughout time (Boyle, 2001). Elemental assemblages present in sediments can be used to infer source areas rich in the same elements. Lake-bottom sediments may be derived dominantly from a single sediment source area or from a number of source areas that have either fixed or shifting proportions.

In a study of south basin shoreline erosion, Penner and Swedlo (1974) concluded that silt and clay sediment inputs to the south basin were an order of magnitude higher for the Red River (2.5×10^6 tons/yr at Lockport) compared with shoreline erosion (2.8×10^5 tons/yr). They also found the contribution of sand and gravel to be greater from shoreline erosion (2.3×10^5 tons/yr) than from the Red River (8×10^4 tons/yr at Lockport). They did not examine inputs from the Winnipeg River or from other sources, as they were deemed insignificant.

Previous elemental analysis of fifty grab samples and thirteen 1-2 m long cores in Lake Winnipeg (Brunskill and Graham, 1979) showed that most of the major element concentrations for these samples were similar to those of Red River suspended sediment samples, implying that much of the lake-bottom sediment was derived from inputs along the Red River rather than from shoreline erosion. The Ca:Mg ratio of the Red River suspended sediment load was consistently less than 1, while that of the lake-bottom samples varied, sometimes to values greater than 1, indicating an additional source of Ca for some sites. Ca, Mg and carbonate carbon exhibited a strong correlation, and the authors concluded that the concentrations of Ca and Mg were controlled by the availability of carbonate minerals, mainly dolomite. While Ca and Mg were more abundant in the silt and sand fractions, Al was strongly correlated with clay content (from clay minerals) and Si was correlated with silt and sand content (quartz and feldspar). Trace element concentrations in lake-bottom sediments varied little, spatially or with depth, and for most elements were similar to the concentrations of Red River suspended sediments.

Henderson and Last (1998) were able to show, from elemental analyses, mineralogical data, and textural data, how the proportions of three distinct sediment source areas for the south basin of Lake Winnipeg have varied during the 4000 years since Lake Winnipeg sedimentation began at their sites. These source areas include Precambrian Shield rocks to the east, Paleozoic carbonate rocks to the west and south, and Cretaceous shales to the southwest. Glaciation reworked these rocks into glacial deposits, which retain much of their original composition. A veneer of glacial deposits covers much of the area surrounding the south basin and provides the main sediment source for former and modern fluvial systems supplying sediment to the basin (Henderson and Last, 1998). Quartz- and feldspar-rich tills derived from the Canadian Shield are dominated by Si, K and Na and higher concentrations of trace elements (Co, Cr, Cu, Ni, Pb and Zn) (Henderson, 1994; Nielsen, 1989). Those derived from the Paleozoic carbonates are dominated by Ca and Mg, hosted by calcite and dolomite, and generally have low trace element concentrations (Henderson, 1994; Nielsen, 1989). Those derived from the Cretaceous shales are rich in aluminum, due to their clay mineral content, and have anomalously high concentrations of V and Zn (Schreiner, 1990), as well as Cd (Garrett, 1994). Lake Agassiz clays, a product of glaciolacustrine reworking of Paleozoic carbonates and Cretaceous shales, underlies a large portion of the Red River valley in southwestern Manitoba and is a significant source of sediment to the Red River.

Henderson and Last (1998) examined the elemental composition of the sediments over a longer time scale than the present study, and provided information on longer-term changes in basin evolution and sediment provenance. They found evidence of transgression, indicated by the upward-decreasing abundance of detrital carbonate minerals, quartz and feldspar. Although the non-detrital carbonate component remained constant throughout the core, the detrital component decreased up-core, hence, the relative proportion of non-detrital (biogenic or authigenic) carbonate minerals increased up-core. In the early stages of inundation by southern Lake Winnipeg, the small size of the lake meant that the input of material from shoreline erosion had a greater influence on sedimentation. As water levels have been gradually rising in the south basin since this time, sedimentation has become increasingly dominated by input from the Red River, while the relative contribution from shoreline erosion has diminished.

Henderson and Last (1998) observed that early south basin sediments have high carbonate content and high V/Al and Zn/Al ratios, derived from Lake Agassiz clays having a Paleozoic and Cretaceous provenance. The upward shift from high to low carbonate content (Ca, total carbonate minerals, calcite and dolomite) and from low to high clay mineral content and trace element concentrations (V, Zn, Cd) is suggestive of a shift in sediments derived from silts with an origin in Paleozoic carbonates to clays derived from Cretaceous shales. They concluded there has been a shift from dominantly-shoreline eroded sediment to domination of fluvially-derived material mainly from the Red River. They also concluded that sediment from the Winnipeg River, which drains an area dominated by Precambrian rocks, was not a significant contributor to south basin sediments.

INTERPRETATION

Long-term trends

The long-term changes that are clear in the 4000-year record are barely perceptible in the 1100-year record of the present study, but can be seen in, for example, upward-diminishing Ca values (Figures 4 and 5).

Applying the findings of Henderson and Last (1998) to the present study, the presence of Ca and Mg, which co-vary, can be used to indicate a provenance more closely associated with shoreline erosion, while the presence of Cd, which co-varies with silt in core 4, could indicate erosion by rivers from Lake Agassiz clays with a Cretaceous provenance. If sedimentation could be thought of as a two-source system, in which, as one component increases the other decreases and vice versa, then Ca and Mg would vary inversely with Cd and silt. However, this is not the case, and some of the broad trends observed in Ca and Mg concentrations are also observed in Cd concentrations. Therefore, it seems reasonable that the process controlling shifts in Cd concentrations and silt also causes shifts in Ca and Mg concentrations, although to a different extent. In some intervals, however, Ca and Mg do behave inversely with Cd and silt content, indicating that during certain times one is more dominant. Most likely, the re-working of sediments of Paleozoic and Cretaceous provenance into Lake Agassiz clays has caused dispersion of distinctive geochemical boundaries.

Anthropogenic change

Increases in Ag, Cd, Cu, Hg, Pb, P, Sb, U and Zn are observed in the uppermost 25 cm of the cores, which corresponds to the post-1900 period (Wilkinson and Simpson, this volume). Elevated concentrations of trace metals (Ag, Cd, Cu, Hg, Pb, Sb, U and Zn) are a concern because they can bioaccumulate in the food chain and pose a risk to human health. Mercury is of particular concern and has been a problem for the fisheries of Lake Winnipeg since the 1970's (Lockhart et al., 2000). Elevated concentrations of P, a key nutrient, contribute to the proliferation of aquatic vegetation and can lead to eutrophication of lake waters.

Increases in the concentrations of these elements recorded in the Lake Winnipeg cores correspond with a time of rapid population growth, increased agriculture, and industrialization in the region. Thus, increases in these contaminants may be attributable, at least partially, to anthropogenic change. Lockhart (1996) and Lockhart et al. (2000) favour an anthropogenic source for 20th century toxic-metal increases in Lake Winnipeg sediments. Rasmussen (1996) cautions against interpreting that all increases of heavy metals are anthropogenic, as background geology and diagenetic cycling processes can also cause increases in these metals. Anthropogenic sources of Hg, Pb, Cu, and Zn include long-range air transport from sources that include coal, oil and wood combustion, nonferrous metal production, steel and iron manufacturing, and refuse incineration (Haygarth and Jones, 1992), as well as local sources.

Lockhart (1996) examined toxic metal concentrations in bottom sediments sampled from Lake Winnipeg. Higher concentrations of Hg, Cd and Pb observed in the south basin are likely the result of differing provenance of the sediments and/or anthropogenic inputs to the south basin. Hg concentrations for 2 long cores, one each from the north and south basins, were also examined and show increases in the top 20 cm. Lockhart et al. (2000) further examined Hg, Cd and Pb concentrations in box cores and long cores collected in 1994 and determined that Hg and Pb concentrations have increased significantly over the past 100 years, although not greatly over the past 20-30 years. Lockhart et al. (2000) concluded that Hg levels in the south basin of Lake Winnipeg were too high to be explained by background geology and atmospheric fallout (coal and petroleum combustion) alone, and that the city of Winnipeg likely provides a significant source of mercury. They found that the Pb profiles were similar to the mercury profiles, and that there was no clear trend for Cd.

Mercury increases in the present study are similar in magnitude to those observed by Lockhart et al. (2000). The 2.4- to 2.7-fold increase in Hg concentrations in the top 25 cm implies that the background geology is not the only contributor to elevated concentrations (Rasmussen et al., 1998), as some researchers attribute a 2- to 5-fold increase in Hg concentration from deep to surface sediments to the 2- to 5-fold increase in atmospheric loading of Hg (Lockhart et al., 1995; Lucotte et al., 1995; Jackson, 1997). However, Rasmussen (1998) found similarities between the shape of vertical mercury profiles and LOI profiles, as well as a lack of correlation between Hg concentrations and sedimentation rates, suggesting that a 2- to 5-fold increase is more likely the result of diagenetic cycling processes. In the present study, Hg concentrations decrease in the top 7 cm, coincident with decreases in worldwide industrial discharges of Hg that began at the end of the 1970's. Given that metal cycling produces maximum concentrations at the surface, increases in Hg concentrations in the Lake Winnipeg cores seems attributable to atmospheric contaminant sources with possible additions from local sources. Indicators of reducing conditions ideal for metal remobilization, such as top-of-core shifts in Fe and Mn, are lacking in the cores, further implying that the observed top-of-core concentrations increases are not simply the result of redox conditions.

Twentieth century increases in Pb have been attributed to atmosphere transport arising from the use of leaded gasoline, and where applicable, to local sources of Pb contamination, provided that background geology and metal recycling can be ruled out (Boyle, 2001). In global inventories of atmospheric Pb emissions by Nrigu and Pacyna (1988) and Nriagu (1989), the proportion of the global atmospheric load arising from industrial sources was estimated at 96 %. The 1100-year record in the cores provides information on pre-industrial Pb concentrations. Remobilization of Pb in the sediment column is unlikely, as Pb does not co-vary with Fe, an indicator of remobilization. Lockhart et al. (2000) concluded that Pb concentrations in Lake Winnipeg sediments, which show significant increases over the past 100 years and subsequent decreases over the past 20-30 years, parallel the use and decline of leaded gasoline. In the present study, increases in Pb were followed by a gradual decrease, likely the result of the conversion to unleaded gasoline in the 1970's in North America (Boutron et al., 1991; Rosman et al., 1994).

Potential causes of P increases are explored by Mayer et al. (this volume). Sources of P include synthetic and natural fertilizers, sewage treatment plant effluent, and septic system effluent. P concentrations in the cores increase more gradually than the metals, suggesting a more gradual increase in contaminant supply, consistent with continued population growth and the expansion of agriculture.

The tendency of top-of-core concentration increases to be recorded in all three cores provides a useful confirmation of core integrity for the uppermost portion of the cores.

CONCLUSIONS

- Many of the 41 elements analyzed show monotonous vertical profiles in the Lake Winnipeg south basin bottom sediments of the past 1100 years.
- Ca, Mg and Cd concentrations show core-to-core decimeter-scale variations.
- Cd shows a strong positive correlation with silt in one of the cores, but this relationship was not duplicated in the other two cores. Nevertheless, peaks in Cd concentration may be useful indicators of influx of sediment from Lake Agassiz clays with a Cretaceous provenance.
- Ca and Mg show a strong positive correlation in all three cores and may be useful for indicating periods when shoreline erosion processes dominated, causing

an influx of sediment derived from Lake Agassiz clays with a Paleozoic provenance.

- Increases in trace metals (Ag, Cd, Cu, Hg, Pb, Sb, U and Zn), as well as P, were observed in the top 25 cm of the cores, corresponding to the 20th century, and some seem attributable to anthropogenic inputs. Concentration increases were greatest for Hg, Ag and Pb. In most cases element concentrations level off or decreases in the top 10 cm, indicating more recent reductions in anthropogenic inputs.

- Significant increases in P are an indication of enhanced nutrient supply.

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Table 1. Methods and detection limits for Lake Winnipeg 99-900 core 3

Element	Decomposition/Method Used	Detection Limit
Al	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	0.2 %
Sb	HF-HNO3-HClO4 decomposition-half dilution-no fusion/ICP-MS	0.05 ppm
Ba	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	10 ppm
Be	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	0.5 ppm
Cd	HF-HNO3-HClO4 decomposition-half dilution-no fusion/ICP-MS	0.05 ppm
Ca	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	0.01 %
Cs	HF-HNO3-HClO4 decomposition-half dilution-no fusion/ICP-MS	0.02 ppm
Cr	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	10 ppm
Co	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	5 ppm
Cu	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	10 ppm
Ga	HF-HNO3-HClO4 decomposition-half dilution-no fusion/ICP-MS	0.1 ppm
Fe	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	0.06 %
Pb	HF-HNO3-HClO4 decomposition-half dilution-no fusion/ICP-MS	0.50 ppm
Mg	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	0.04 %
Mn	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	0.01 %
Mo	HF-HNO3-HClO4 decomposition-half dilution-no fusion/ICP-MS	0.05 ppm
Ni	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	10 ppm
Nb	HF-HNO3-HClO4 decomposition-half dilution-no fusion/ICP-MS	0.02 ppm
P	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	0.01 %
K	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	0.10 %
Rb	HF-HNO3-HClO4 decomposition-half dilution-no fusion/ICP-MS	0.05 ppm
Ag	HF-HNO3-HClO4 decomposition-half dilution-no fusion/ICP-MS	0.02 ppm
Na	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	0.10 %
Sr	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	5 ppm
Ta	HF-HNO3-HClO4 decomposition-half dilution-no fusion/ICP-MS	0.02 ppm
Tl	HF-HNO3-HClO4 decomposition-half dilution-no fusion/ICP-MS	0.02 ppm
Th	HF-HNO3-HClO4 decomposition-half dilution-no fusion/ICP-MS	0.02 ppm
Ti	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	0.02 %
U	HF-HNO3-HClO4 decomposition-half dilution-no fusion/ICP-MS	0.02 ppm
V	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	5 ppm
Y	HF-HNO3-HClO4 decomposition-half dilution-no fusion/ICP-MS	0.02 ppm
Zn	HF-HNO3-HClO4 decomposition-no fusion/ICP-ES	5 ppm

Table 2. Methods and detection limits for Lake Winnipeg 99-900 cores 4 and 8

Element	Decomposition/Method Used	Detection Limit
As	aqua regia decomposition/AAS-HYDRIDE/EDL method	1 ppm
Hg	aqua regia decomposition/CV-AAS method	10 ppb
Al	HF-HNO3-HClO4 decomposition/ICP-ES method	0.01 %
Sb	HF-HNO3-HClO4 decomposition/ICP-MS method	0.1 ppm
Ba	HF-HNO3-HClO4 decomposition/ICP-ES method	10 ppm
Be	HF-HNO3-HClO4 decomposition/ICP-MS/ICP-ES method	0.05 ppm
Bi	HF-HNO3-HClO4 decomposition/ICP-MS/ICP-ES method	0.01 ppm
Cd	HF-HNO3-HClO4 decomposition/ICP-MS/ICP-ES method	0.02 ppm
Ca	HF-HNO3-HClO4 decomposition/ICP-ES method	0.01 %
Ce	HF-HNO3-HClO4 decomposition/ICP-MS method	0.01 ppm
Cs	HF-HNO3-HClO4 decomposition/ICP-MS method	0.05 ppm
Cr	HF-HNO3-HClO4 decomposition/ICP-ES method	1 ppm
Co	HF-HNO3-HClO4 decomposition/ICP-MS/ICP-ES method	0.2 ppm
Cu	HF-HNO3-HClO4 decomposition/ICP-ES method	1 ppm
Ga	HF-HNO3-HClO4 decomposition/ICP-MS method	0.1 ppm
Ge	HF-HNO3-HClO4 decomposition/ICP-MS method	0.1 ppm
Fe	HF-HNO3-HClO4 decomposition/ICP-ES method	0.01 %
La	HF-HNO3-HClO4 decomposition/ICP-MS method	0.5 ppm
Pb	HF-HNO3-HClO4 decomposition/ICP-MS/ICP-ES method	0.5 ppm
Li	HF-HNO3-HClO4 decomposition/ICP-MS method	0.2 ppm
Mg	HF-HNO3-HClO4 decomposition/ICP-ES method	0.01 %
Mn	HF-HNO3-HClO4 decomposition/ICP-ES method	5 ppm
Mo	HF-HNO3-HClO4 decomposition/ICP-ES method	0.2 ppm
Ni	HF-HNO3-HClO4 decomposition/ICP-MS/ICP-ES method	0.2 ppm
Nb	HF-HNO3-HClO4 decomposition/ICP-MS method	0.2 ppm
P	HF-HNO3-HClO4 decomposition/ICP-ES method	10 ppm
K	HF-HNO3-HClO4 decomposition/ICP-ES method	0.01 %
Rb	HF-HNO3-HClO4 decomposition/ICP-MS method	0.2 ppm
Ag	HF-HNO3-HClO4 decomposition/ICP-MS/ICP-ES method	0.05 ppm
Na	HF-HNO3-HClO4 decomposition/ICP-ES method	0.01 %
Sr	HF-HNO3-HClO4 decomposition/ICP-MS/ICP-ES method	0.2 ppm
Ta	HF-HNO3-HClO4 decomposition/ICP-MS method	0.05 ppm
Te	HF-HNO3-HClO4 decomposition/ICP-MS method	0.05 ppm
Tl	HF-HNO3-HClO4 decomposition/ICP-MS method	0.02 ppm
Th	HF-HNO3-HClO4 decomposition/ICP-MS method	0.2 ppm
Ti	HF-HNO3-HClO4 decomposition/ICP-ES method	0.01 %
W	HF-HNO3-HClO4 decomposition/ICP-MS/ICP-ES method	0.1 ppm
U	HF-HNO3-HClO4 decomposition/ICP-MS method	0.2 ppm
V	HF-HNO3-HClO4 decomposition/ICP-ES method	1 ppm
Y	HF-HNO3-HClO4 decomposition/ICP-MS method	0.1 ppm
Zn	HF-HNO3-HClO4 decomposition/ICP-ES method	2 ppm

Table 3. Type of analytical trend

Element	Core 3	Core 4	Core 8
As	--	D	D
Hg	--	B	B
Al	C	A	A
Sb	A	D	B
Ba	A	C	A
Be	C	A	A
Bi	--	C	A/C
Cd	C	C	A
Ca	A	A	A
Ce	--	A/C	A/C
Cs	C	A/C	C
Cr	A	A	B
Co	A	C	A
Cu	A	A	A
Ga	A	C	A
Ge	--	C	C
Fe	C	A	A
La	--	C	C
Pb	A	B/C	B
Li	--	A/C	A/C
Mg	C	A	A
Mn	A	B	B
Mo	A	D	B
Ni	A	A	A
Nb	C	C	C
P	A	B	B
K	C	A	A
Rb	B	A	C
Ag	C	B	B
Na	C	A	C
Sr	B	A/C	A
Ta	A	C	A
Te	--	D	D
Tl	A/C	C	A
Th	C	C	A
Ti	A	A	C
W	--	D	B
U	A	C	C
V	B	A	A
Y	C	C	C
Zn	A	A	A

Table 4. Duplicate analyses for Lake Winnipeg 99-900 core 3

	Al wt%		Sb ppm		Ba ppm		Be ppm		Cd ppm		Ca wt%		Cs ppm		Cr ppm		Co ppm		Cu ppm	
Sample No	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Core-3-5-6 cm	8.92	8.94	0.9	0.9	624	632	2.4	2.6	0.64	0.69	1.24	1.24	7.49	7.50	135	137	19.1	20.0	36	38
Core-3-10-11 cm	9.07	8.89	0.8	0.8	634	616	2.5	2.6	0.56	0.57	1.19	1.14	7.79	7.70	121	115	19.7	20.0	40	39
Core-3-35-36 cm	8.97	8.99	0.7	0.7	649	655	2.5	2.6	0.47	0.58	1.10	1.11	7.39	7.40	116	109	21.0	21.0	31	34
Core-3-40-41 cm	9.13	9.20	0.7	0.7	672	673	2.5	2.6	0.54	0.48	1.09	1.09	7.79	7.90	120	113	18.5	19.0	33	34
Core-3-44-45 cm	9.23	8.78	0.7	0.7	662	648	2.5	2.4	0.56	0.53	1.09	1.08	7.63	7.40	142	123	20.4	20.0	34	32
Core-3-70-71 cm	8.86	8.89	0.7	0.7	662	667	2.5	2.4	0.52	0.50	1.17	1.18	7.53	7.30	113	118	20.6	20.0	33	32
Core-3-89-90 cm	9.24	9.26	0.8	0.8	685	684	2.5	2.6	0.65	0.50	1.13	1.13	7.53	7.60	110	120	22.3	22.0	35	34
Core-3-94-95cm	9.08	9.20	0.7	0.7	679	681	2.5	2.6	0.44	0.41	1.06	1.05	7.69	7.70	129	122	21.8	21.0	34	34
RSD	1.40 %		1.8 %		1 %		3.3 %		9.60 %		1.19 %		1.19 %		5 %		1.9 %		3 %	
Precision	2.80 %		3.6 %		2 %		6.6 %		19.20 %		2.38 %		2.39 %		11 %		3.8 %		7 %	

	Ga ppm		Fe wt%		Pb ppm		Mn wt%		Mg wt%		Mo ppm		Ni ppm		Nb ppm		P wt%		K wt%	
Sample No	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Core-3-5-6 cm	23.0	23.0	5.14	5.19	27.0	28.0	0.12	0.12	1.64	1.65	0.9	0.9	58.0	59.0	14.0	14.0	0.08	0.09	2.16	2.10
Core-3-10-11 cm	23.0	22.0	5.15	5.07	26.0	26.0	0.13	0.12	1.62	1.60	0.8	0.7	60.0	58.0	14.0	13.0	0.08	0.08	2.13	2.13
Core-3-35-36 cm	23.0	23.0	5.08	5.15	21.0	21.0	0.14	0.14	1.58	1.60	0.9	0.9	60.0	60.0	14.0	15.0	0.07	0.07	2.12	2.16
Core-3-40-41 cm	23.0	23.0	5.22	5.25	22.0	21.0	0.15	0.15	1.59	1.61	0.8	0.7	58.0	58.0	14.0	14.0	0.07	0.07	2.16	2.21
Core-3-44-45 cm	23.0	23.0	5.16	4.98	21.0	21.0	0.13	0.12	1.60	1.56	0.8	0.8	60.0	59.0	14.0	14.0	0.07	0.07	2.15	2.13
Core-3-70-71 cm	22.0	22.0	4.94	4.88	21.0	20.0	0.14	0.14	1.59	1.57	0.9	0.8	59.0	59.0	14.0	13.0	0.07	0.07	2.13	2.16
Core-3-89-90 cm	23.0	23.0	5.20	5.24	20.0	20.0	0.15	0.15	1.64	1.65	1.0	0.9	68.0	65.0	14.0	14.0	0.07	0.07	2.20	2.22
Core-3-94-95cm	24.0	23.0	5.20	5.21	20.0	20.0	0.12	0.12	1.59	1.60	1.0	1.0	61.0	61.0	14.0	13.0	0.07	0.07	2.17	2.18
RSD	1.6 %		1.12 %		2.0 %		2.64 %		0.92 %		4.6 %		1.6 %		3.6 %		3.42 %		1.13 %	
Precision	3.1 %		2.23 %		3.9 %		5.29 %		1.84 %		9.2 %		3.2 %		7.2 %		6.84 %		2.26 %	

Table 4 continued

Sample No	Rb ppm 1st	Rb ppm 2nd	Ag ppm 1st	Ag ppm 2nd	Na wt% 1st	Na wt% 2nd	Sr ppm 1st	Sr ppm 2nd	Ta ppm 1st	Ta ppm 2nd	Tl ppm 1st	Tl ppm 2nd	Th ppm 1st	Th ppm 2nd	Ti wt% 1st	Ti wt% 2nd	U ppm 1st	U ppm 2nd
Core-3-5-6 cm	136.0	133.0	0.27	0.27	0.56	0.55	130.0	130.0	0.89	0.91	0.91	0.90	12.7	14.0	0.38	0.37	3.3	3.4
Core-3-10-11 cm	135.0	129.0	0.25	0.24	0.56	0.56	131.0	127.0	0.93	0.97	0.95	1.00	13.7	14.0	0.40	0.38	3.3	3.5
Core-3-35-36 cm	129.0	130.0	0.17	0.18	0.54	0.54	129.0	130.0	1.00	0.99	0.98	0.95	12.7	13.0	0.39	0.40	2.8	3.0
Core-3-40-41 cm	130.0	137.0	0.16	0.18	0.55	0.58	134.0	132.0	0.97	0.96	0.97	0.98	13.7	14.0	0.39	0.39	2.9	3.0
Core-3-44-45 cm	136.0	133.0	0.17	0.17	0.59	0.57	133.0	131.0	0.95	0.91	0.94	0.91	13.5	13.0	0.39	0.37	2.8	2.7
Core-3-70-71 cm	127.0	128.0	0.16	0.16	0.60	0.61	131.0	132.0	0.99	0.92	0.96	0.90	12.5	12.0	0.39	0.38	2.9	2.6
Core-3-89-90 cm	130.0	134.0	0.19	0.16	0.57	0.58	132.0	132.0	0.95	0.92	0.94	0.95	12.5	13.0	0.40	0.39	2.9	2.8
Core-3-94-95cm	140.0	133.0	0.16	0.09	0.56	0.57	130.0	130.0	0.98	0.96	0.97	0.99	13.7	14.0	0.39	0.38	2.8	2.8
RSD	2.5 %		10.70 %		1.81 %		1.0 %		2.63 %		2.44 %		3.1 %		2.33 %		4.1 %	
Precision	4.9 %		21.48 %		3.63 %		2.0 %		5.26 %		4.88 %		6.2 %		4.66 %		8.2 %	

Sample No	V ppm 1st	V ppm 2nd	Y ppm 1st	Y ppm 2nd	Zn ppm 1st	Zn ppm 2nd
Core-3-5-6 cm	202	200	22.8	22.0	153	158
Core-3-10-11 cm	205	198	22.8	22.0	158	152
Core-3-35-36 cm	208	209	22.8	23.0	146	145
Core-3-40-41 cm	213	211	22.8	24.0	147	146
Core-3-44-45 cm	206	204	23.5	23.0	146	145
Core-3-70-71 cm	201	205	23.5	22.0	144	145
Core-3-89-90 cm	212	209	21.5	22.0	146	145
Core-3-94-95cm	206	205	22.8	22.0	143	144
RSD	1 %		2.7 %		1 %	
Precision	2 %		5.4 %		3 %	

Table 5. Duplicate analyses using AAS-HYDRIDE/EDL method with aqua regia decomposition for Lake Winnipeg 99-900 cores 4 and 8

	As ppm	
Sample No	**1st**	**2nd**
Core-4-102-103cm	<1	3
Core-4-121-122cm	5	3
Core-4-133-134cm	3	3
Core-4-140-141cm	<1	3
Core-4-156-157cm	<1	3
Core-4-160-161cm	<1	1
Core-4-46-47cm	<1	3
Core-4-62-63cm	<1	1
Core-4-74-75cm	4	3
Core-4-84-85cm	5	3
Core-4-98-99cm	3	3
Core-8-101-102cm	3	3
Core-8-114-115cm	4	3
Core-8-121-122cm	3	1
Core-8-133-134cm	1	1
Core-8-147-148cm	4	<1
Core-8-25-26cm	3	<1
Core-8-35-36cm	4	<1
Core-8-38-39cm	3	<1
Core-8-50-51cm	4	1
Core-8-59-60cm	1	<1
Core-8-74-75cm	3	1
Core-8-86-87cm	3	2
RSD	63 %	
Precision	126 %	

Table 6. Duplicate analyses using CV-AAS method with aqua regia decomposition for Lake Winnipeg 99-900 cores 4 and 8

	Hg ppb	
Sample No	**1st**	**2nd**
Core-4-102-103cm	30	70
Core-4-121-122cm	30	50
Core-4-133-134cm	40	50
Core-4-140-141cm	40	40
Core-4-156-157cm	40	50
Core-4-160-161cm	50	40
Core-4-46-47cm	40	50
Core-4-62-63cm	40	40
Core-4-74-75cm	60	40
Core-4-84-85cm	40	60
Core-4-98-99cm	40	50
Core-8-101-102cm	50	60
Core-8-114-115cm	50	50
Core-8-121-122cm	40	50
Core-8-133-134cm	50	50
Core-8-147-148cm	50	50
Core-8-25-26cm	50	60
Core-8-35-36cm	50	60
Core-8-38-39cm	50	60
Core-8-50-51cm	50	60
Core-8-59-60cm	40	50
Core-8-74-75cm	50	60
Core-8-86-87cm	60	50
RSD	20 %	
Precision	39 %	

Table 7. Duplicate analyses using ICP-ES method with HF-HNO3-HClO4 (near total) decomposition for Lake Winnipeg 99-900 cores 4 and 8

	Al		Ba		Ca		Cr		Cu		Fe		K		Mg		Mn		Mo	
	wt%		ppm		wt%		ppm		ppm		wt%		wt%		wt%		ppm		ppm	
Sample No	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**
Core-4-102-103cm	8.29	8.79	500	690	1.08	0.99	99	100	28	30	3.99	4.37	1.88	1.95	1.42	1.48	1205	1300	0.8	0.8
Core-4-121-122cm	8.62	8.68	550	690	0.98	0.90	113	123	28	27	4.11	4.29	2.19	1.94	1.41	1.43	1165	1205	1.0	1.2
Core-4-133-134cm	7.90	8.64	480	650	1.24	1.18	93	97	26	27	3.78	4.04	1.79	1.85	1.46	1.56	1125	1240	0.8	0.8
Core-4-140-141cm	8.43	8.72	520	680	1.18	1.09	96	97	29	28	4.00	4.27	1.86	1.94	1.51	1.53	1120	1180	2.6	0.8
Core-4-156-157cm	8.57	8.61	540	670	1.34	1.23	101	93	29	26	3.95	4.19	2.04	1.91	1.63	1.59	1195	1230	0.8	0.8
Core-4-160-161cm	8.22	8.69	520	720	1.23	1.15	96	94	30	27	3.99	4.20	2.06	1.96	1.52	1.59	1065	1140	1.6	0.8
Core-4-46-47cm	8.35	9.40	510	690	1.21	1.22	103	109	26	28	4.04	4.54	2.04	2.09	1.51	1.65	1210	1360	2.2	1.0
Core-4-62-63cm	8.53	8.98	520	690	1.02	0.96	99	112	27	26	4.12	4.30	1.96	1.97	1.44	1.48	1245	1325	0.8	1.0
Core-4-74-75cm	8.43	9.01	550	700	1.08	1.03	100	100	26	27	3.90	4.35	2.12	2.03	1.43	1.49	1300	1410	0.8	0.8
Core-4-84-85cm	7.85	8.54	510	550	1.11	1.06	95	95	27	27	3.84	4.15	2.04	1.94	1.39	1.51	1300	1430	0.8	1.0
Core-4-98-99cm	8.44	8.88	530	760	1.03	0.96	100	96	30	28	4.09	4.35	1.92	1.88	1.44	1.49	1270	1370	0.8	1.2
Core-8-101-102cm	8.05	8.44	630	880	1.33	1.32	116	88	27	25	3.95	4.10	1.91	1.87	1.58	1.58	1335	1335	1.2	1.0
Core-8-114-115cm	7.92	8.40	590	900	1.24	1.24	92	95	27	26	3.69	3.99	1.96	1.92	1.50	1.55	1620	1760	1.0	1.4
Core-8-121-122cm	8.00	8.57	630	740	1.53	1.57	92	94	24	25	3.78	4.04	1.90	1.96	1.71	1.76	1250	1320	0.8	1.0
Core-8-133-134cm	7.97	8.38	610	510	1.50	1.49	118	90	26	24	3.73	3.83	1.90	1.87	1.69	1.70	1185	1230	1.4	1.0
Core-8-147-148cm	7.86	8.55	580	480	1.34	1.38	91	92	29	26	3.71	4.06	1.96	1.94	1.55	1.70	1110	1230	0.8	0.6
Core-8-25-26cm	8.19	8.87	610	820	1.18	1.21	97	95	26	26	4.06	4.32	1.96	1.97	1.49	1.60	1120	1240	0.8	0.8
Core-8-35-36cm	7.69	8.56	550	820	1.29	1.34	137	91	28	24	3.78	4.16	1.93	1.92	1.50	1.63	1130	1215	1.2	0.8
Core-8-38-39cm	7.99	8.83	600	760	1.28	1.32	94	94	24	25	4.01	4.32	1.91	1.99	1.52	1.62	1155	1280	0.8	0.8
Core-8-50-51cm	7.86	8.60	580	720	1.43	1.44	89	88	25	24	3.67	4.07	1.95	1.93	1.60	1.69	1205	1335	1.0	0.8
Core-8-59-60cm	8.56	8.74	660	690	1.15	1.15	97	92	26	26	4.20	4.12	1.99	1.97	1.54	1.54	1280	1335	0.8	0.8
Core-8-74-75cm	8.16	8.81	640	860	1.28	1.31	95	90	26	26	4.06	4.28	1.93	1.95	1.57	1.65	1270	1365	1.0	1.0
Core-8-86-87cm	8.18	8.69	610	700	1.21	1.21	94	90	25	25	4.05	4.21	1.93	1.94	1.49	1.55	1225	1335	0.8	0.8
RSD	4.93 %		20 %		3.15 %		10 %		5 %		5.04 %		2.85 %		3.65 %		5 %		37.2 %	
Precision	9.85 %		39 %		6.30 %		19 %		9 %		10.07 %		5.70 %		7.30 %		11 %		74.3 %	

Table 7 continued

	Na		P		Ti		V		Zn	
	wt%		ppm		wt%		ppm		ppm	
Sample No	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**
Core-4-102-103cm	0.66	0.54	690	640	0.34	0.38	205	202	126	118
Core-4-121-122cm	0.67	0.56	870	810	0.35	0.37	204	195	124	110
Core-4-133-134cm	0.70	0.59	680	680	0.33	0.38	189	186	120	108
Core-4-140-141cm	0.71	0.58	700	670	0.36	0.38	202	192	122	108
Core-4-156-157cm	0.73	0.60	710	620	0.37	0.38	195	186	122	102
Core-4-160-161cm	0.71	0.59	690	660	0.36	0.37	199	194	120	106
Core-4-46-47cm	0.67	0.60	680	710	0.36	0.41	204	211	124	118
Core-4-62-63cm	0.65	0.55	690	660	0.35	0.39	211	203	126	112
Core-4-74-75cm	0.71	0.60	680	690	0.36	0.38	202	203	122	116
Core-4-84-85cm	0.71	0.63	730	700	0.34	0.37	193	189	122	106
Core-4-98-99cm	0.66	0.61	700	670	0.35	0.40	205	194	128	108
Core-8-101-102cm	0.54	0.57	690	640	0.35	0.38	199	188	118	104
Core-8-114-115cm	0.69	0.58	710	700	0.31	0.36	186	192	116	108
Core-8-121-122cm	0.52	0.56	640	660	0.34	0.33	194	194	116	114
Core-8-133-134cm	0.54	0.57	670	620	0.34	0.37	191	183	118	104
Core-8-147-148cm	0.70	0.59	710	640	0.33	0.38	184	189	112	104
Core-8-25-26cm	0.56	0.58	660	670	0.35	0.38	187	194	118	110
Core-8-35-36cm	0.66	0.59	680	660	0.32	0.39	191	184	118	104
Core-8-38-39cm	0.54	0.60	680	640	0.34	0.38	190	192	114	104
Core-8-50-51cm	0.86	0.59	1060	660	0.29	0.36	187	193	114	104
Core-8-59-60cm	0.57	0.57	660	640	0.37	0.38	201	195	116	106
Core-8-74-75cm	0.56	0.61	660	660	0.37	0.40	193	189	112	104
Core-8-86-87cm	0.53	0.57	660	630	0.34	0.37	195	193	118	104
RSD	11.66 %		9 %		7.54 %		2 %		8 %	
Precision	23.31 %		19 %		15.08 %		5 %		15 %	

Table 8. Duplicate analyses using ICP-MS method with HF-HNO3-HClO4 (near total) decomposition for Lake Winnipeg 99-900 cores 4 and 8

	Ce		Cs		Ga		Ge		La		Li		Nb		Rb		Sb		Ta	
	ppm		ppm		ppm		ppm		ppm		ppm		ppm		ppm		ppm		ppm	
Sample No	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**
Core-4-102-103cm	71.0	71.5	7.45	7.35	24.3	22.0	1.7	1.6	38.0	41.0	62.6	53.2	12.6	14.4	105.5	125.0	0.4	0.9	0.75	0.95
Core-4-121-122cm	75.3	72.5	8.05	7.15	23.4	21.3	1.6	1.5	40.0	41.5	59.0	49.2	12.8	13.6	118.0	119.5	0.7	0.8	0.90	1.00
Core-4-133-134cm	72.0	73.1	7.10	7.10	24.2	20.6	1.7	1.5	38.5	41.0	60.2	46.2	12.8	13.6	108.5	115.5	0.4	0.9	0.80	1.05
Core-4-140-141cm	68.7	68.1	7.00	6.75	22.1	20.2	1.6	1.5	39.5	38.5	56.2	47.2	14.2	13.0	109.0	115.5	0.9	0.9	0.95	0.95
Core-4-156-157cm	76.5	75.7	7.45	7.05	23.1	21.7	1.5	1.5	40.0	42.0	59.6	50.0	13.4	14.4	112.0	120.5	0.6	0.8	0.85	1.00
Core-4-160-161cm	69.1	71.7	6.80	7.10	21.4	21.0	1.5	1.5	39.0	40.5	55.0	47.8	13.8	13.6	110.0	120.0	0.9	1.0	1.00	0.95
Core-4-46-47cm	71.0	75.2	7.10	7.45	22.2	21.6	1.6	1.6	40.0	42.5	58.0	48.6	14.6	14.6	114.5	124.0	0.9	0.9	1.05	1.05
Core-4-62-63cm	67.6	72.0	7.25	7.45	22.2	21.8	1.6	1.6	38.5	41.5	58.6	50.2	13.8	14.4	112.5	123.5	0.8	0.8	1.00	1.05
Core-4-74-75cm	74.2	75.6	7.75	7.55	22.7	21.5	1.6	1.6	39.5	42.5	59.8	46.0	13.4	13.6	113.0	121.5	0.7	0.8	0.90	1.05
Core-4-84-85cm	78.0	66.2	7.25	7.35	24.1	20.6	1.7	1.7	40.0	39.5	59.2	44.2	13.6	14.6	110.5	120.0	0.5	1.2	0.80	0.35
Core-4-98-99cm	76.3	69.5	7.55	8.10	23.8	22.8	1.7	1.8	40.5	42.0	59.6	51.2	13.0	15.4	106.0	129.0	0.5	1.4	0.85	0.35
Core-8-101-102cm	67.2	66.1	6.60	7.80	21.0	21.6	1.5	1.7	38.0	40.0	54.8	48.4	13.8	14.6	113.5	121.0	0.8	1.8	0.90	0.35
Core-8-114-115cm	68.8	67.7	6.45	7.50	21.6	20.9	1.8	1.5	38.0	40.0	54.0	47.2	12.0	15.0	111.5	118.0	0.9	3.2	0.95	0.25
Core-8-121-122cm	64.9	64.1	6.70	6.90	20.3	18.8	1.4	1.5	37.0	34.0	52.2	43.8	13.4	12.2	113.5	111.5	0.9	4.5	0.90	0.30
Core-8-133-134cm	63.4	63.4	6.30	7.70	20.3	20.4	1.5	1.6	35.5	38.0	54.2	47.2	13.2	12.8	110.0	123.0	0.8	0.7	0.90	0.35
Core-8-147-148cm	65.9	69.9	5.95	7.15	21.6	19.1	1.8	1.5	36.5	37.0	54.2	42.6	12.8	12.0	102.0	116.0	1.0	0.7	1.05	0.35
Core-8-25-26cm	68.0	71.4	6.65	6.95	21.2	20.4	1.5	1.5	38.5	40.0	54.8	44.6	14.0	13.6	117.5	118.5	0.8	0.9	0.95	1.00
Core-8-35-36cm	59.4	71.9	4.60	6.90	20.3	20.4	1.6	1.4	33.0	40.5	48.8	45.4	11.8	14.0	82.8	116.5	0.8	2.1	0.95	1.00
Core-8-38-39cm	68.6	73.4	6.75	7.20	21.9	20.8	1.6	1.6	39.0	41.5	56.2	45.2	13.8	13.0	118.0	120.0	0.8	0.9	0.90	1.05
Core-8-50-51cm	66.0	70.9	6.75	7.05	21.1	19.5	1.7	1.5	37.0	39.5	53.2	42.4	12.2	13.0	113.5	113.5	1.0	1.4	1.00	1.00
Core-8-59-60cm	71.9	75.5	7.15	7.60	21.6	20.7	1.6	1.5	40.5	42.5	55.0	43.0	14.2	13.8	119.5	121.0	0.8	1.2	1.00	1.10
Core-8-74-75cm	73.3	77.8	7.00	7.40	21.1	21.0	1.6	1.6	41.5	43.5	54.4	44.8	14.8	14.4	119.5	119.0	0.9	0.9	1.00	1.10
Core-8-86-87cm	64.4	74.0	6.70	7.40	21.1	20.9	1.6	1.6	36.0	41.5	55.4	45.4	12.6	14.0	115.0	120.5	0.8	0.9	0.85	1.10
RSD	5.1 %		7.82 %		5.2 %		6.0 %		5.1 %		13.7 %		6.4 %		7.2 %		69.3 %		27.78 %	
Precision	10.3 %		15.64 %		10.5 %		11.9 %		10.1 %		27.3 %		12.8 %		14.4 %		138.6 %		55.55 %	

Table 8 continued

	Te		Th		Tl		U		Y	
	ppm		ppm		ppm		ppm		ppm	
Sample No	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Core-4-102-103cm	0.10	0.10	12.8	14.2	0.62	0.76	2.6	2.8	19.5	19.7
Core-4-121-122cm	0.05	0.15	14.0	13.6	0.72	0.72	2.8	2.6	20.4	19.2
Core-4-133-134cm	0.10	0.10	13.2	14.0	0.60	0.70	2.6	2.8	20.3	19.5
Core-4-140-141cm	0.10	0.10	14.4	13.0	0.64	0.68	2.8	2.4	19.4	18.8
Core-4-156-157cm	0.10	0.05	13.6	14.2	0.70	0.70	2.8	2.6	21.0	20.2
Core-4-160-161cm	0.05	0.05	14.0	13.6	0.68	0.72	2.8	2.6	18.7	19.3
Core-4-46-47cm	0.05	0.05	14.4	14.2	0.72	0.78	3.0	2.8	19.9	20.5
Core-4-62-63cm	0.10	0.05	13.8	13.8	0.70	0.74	2.8	2.6	19.0	19.7
Core-4-74-75cm	0.10	0.05	13.4	14.0	0.72	0.76	2.6	2.6	20.5	19.4
Core-4-84-85cm	0.15	0.15	13.4	12.0	0.66	0.80	2.6	2.6	21.0	20.3
Core-4-98-99cm	0.10	0.10	13.8	13.2	0.66	0.88	2.6	3.0	20.0	21.2
Core-8-101-102cm	0.10	0.10	13.4	12.0	0.68	0.84	2.6	3.0	19.2	20.7
Core-8-114-115cm	0.10	0.10	14.2	12.0	0.70	0.86	2.8	2.8	19.7	21.0
Core-8-121-122cm	0.15	0.05	12.6	10.4	0.66	0.72	2.6	2.4	18.4	17.6
Core-8-133-134cm	0.05	0.05	12.4	11.4	0.64	0.76	2.6	2.6	18.2	19.8
Core-8-147-148cm	0.15	0.05	13.8	10.8	0.72	0.72	3.0	2.4	18.4	18.3
Core-8-25-26cm	0.10	0.05	13.2	13.4	0.70	0.72	2.8	2.6	19.4	19.1
Core-8-35-36cm	0.05	0.15	12.2	13.2	0.66	0.72	2.8	2.6	16.3	19.4
Core-8-38-39cm	0.10	0.10	13.2	13.6	0.66	0.72	2.6	2.6	19.4	19.9
Core-8-50-51cm	0.10	0.15	14.0	13.0	0.74	0.72	3.0	2.6	19.3	18.7
Core-8-59-60cm	0.05	0.15	14.2	14.4	0.74	0.76	2.8	2.8	19.8	19.5
Core-8-74-75cm	0.05	0.15	14.2	14.4	0.74	0.76	2.8	2.8	20.3	20.1
Core-8-86-87cm	0.10	0.15	12.8	13.4	0.68	0.72	2.6	2.6	18.7	19.8
RSD	43.20 %		6.3 %		8.89 %		6.5 %		3.9 %	
Precision	86.39 %		12.6 %		17.78 %		12.9 %		7.7 %	

Table 9. Duplicate analyses using ICP-MS/ICP-ES method with HF-HNO3-HClO4 (near total) decomposition for Lake Winnipeg 99-900 cores 4 and 8

	Ag		Be		Bi		Cd		Co		Ni		Pb		Sr		W	
	ppm		ppm		ppm		ppm		ppm		ppm		ppm		ppm		ppm	
Sample No	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Core-4-102-103cm	0.55	0.55	2.05	2.10	0.40	0.29	0.44	0.44	16.4	18.4	47.7	46.8	19.0	20.0	129.0	126.0	1.0	1.3
Core-4-121-122cm	0.60	0.50	2.15	1.95	0.42	0.30	0.44	0.42	16.0	17.4	58.7	54.8	20.0	19.0	133.0	123.5	1.2	1.4
Core-4-133-134cm	0.60	0.60	2.00	2.10	0.39	0.31	0.52	0.54	18.2	18.8	47.1	45.8	19.0	20.5	132.5	127.5	1.1	1.4
Core-4-140-141cm	0.55	0.55	2.05	2.05	0.32	0.29	0.46	0.44	18.8	17.4	47.4	45.0	20.0	20.0	133.0	124.5	1.5	1.2
Core-4-156-157cm	0.65	0.55	1.85	1.85	0.42	0.31	0.46	0.48	17.0	19.0	50.1	48.8	22.0	21.0	141.5	130.0	1.2	1.4
Core-4-160-161cm	0.55	0.55	2.05	1.90	0.33	0.30	0.46	0.42	17.4	17.8	45.0	46.2	19.5	19.5	130.0	128.0	1.7	1.4
Core-4-46-47cm	0.50	0.55	2.25	2.15	0.38	0.31	0.52	0.50	20.2	20.2	48.8	52.1	21.0	20.5	129.0	132.0	1.6	1.5
Core-4-62-63cm	0.50	0.60	2.15	2.20	0.32	0.32	0.42	0.38	18.2	18.2	45.8	52.0	19.5	20.0	129.0	125.0	1.8	1.4
Core-4-74-75cm	0.55	0.55	1.90	2.30	0.40	0.32	0.40	0.42	16.0	17.8	48.5	45.0	19.0	20.5	133.0	128.5	1.2	1.4
Core-4-84-85cm	0.55	0.65	2.55	1.70	0.42	0.39	0.56	0.56	17.8	18.0	45.3	54.0	20.5	21.5	138.5	132.5	1.2	1.5
Core-4-98-99cm	0.60	0.60	2.45	2.00	0.42	0.40	0.48	0.52	17.6	19.6	51.5	59.4	19.5	22.0	135.0	136.0	1.2	1.4
Core-8-101-102cm	0.50	0.60	2.05	1.85	0.30	0.39	0.54	0.60	18.6	18.4	53.9	56.4	19.0	21.0	127.5	132.5	1.4	1.4
Core-8-114-115cm	0.45	0.65	2.05	1.75	0.33	0.39	0.58	0.58	19.0	19.4	47.6	59.4	21.5	21.5	129.0	134.0	1.2	1.4
Core-8-121-122cm	0.55	0.50	2.15	1.70	0.29	0.33	0.46	0.86	17.4	15.4	42.4	47.4	19.0	18.0	121.0	111.5	1.2	1.2
Core-8-133-134cm	0.50	0.55	1.70	1.65	0.28	0.37	0.48	0.56	18.8	18.6	52.4	55.4	17.5	21.0	123.5	126.0	1.3	1.2
Core-8-147-148cm	0.45	0.55	1.85	1.45	0.32	0.33	0.50	0.78	17.2	16.0	43.4	51.6	21.0	19.0	124.0	120.5	1.4	1.1
Core-8-25-26cm	0.50	0.55	2.10	2.05	0.29	0.31	0.44	0.46	18.8	17.8	45.8	43.8	20.0	20.5	123.0	125.5	1.2	1.4
Core-8-35-36cm	0.50	0.55	1.75	2.00	0.30	0.30	0.46	0.44	17.4	18.4	51.9	43.6	20.0	20.0	112.0	126.0	1.4	1.4
Core-8-38-39cm	0.50	0.55	2.40	2.00	0.29	0.31	0.50	0.50	19.6	18.4	46.8	45.0	19.0	21.0	126.0	127.5	1.2	1.3
Core-8-50-51cm	0.45	0.55	2.15	1.95	0.33	0.30	0.58	0.56	17.0	16.4	42.8	41.4	21.0	20.0	124.5	125.0	1.3	1.4
Core-8-59-60cm	0.55	0.60	2.10	1.80	0.31	0.33	0.50	0.48	18.2	17.0	45.0	43.0	21.5	23.5	124.5	125.5	1.4	1.6
Core-8-74-75cm	0.55	0.55	2.25	1.80	0.32	0.34	0.54	0.54	19.0	18.2	46.8	45.4	21.0	21.5	128.5	128.5	1.4	1.5
Core-8-86-87cm	0.45	0.60	1.95	2.00	0.28	0.31	0.54	0.52	19.2	18.6	47.2	47.2	18.5	21.0	123.0	124.5	1.1	1.4
RSD	10.42 %		10.97 %		12.78 %		14.79 %		4.6 %		7.2 %		5.3 %		3.2 %		11.6 %	
Precision	20.85 %		21.95 %		25.56 %		29.57 %		9.2 %		14.3 %		10.5 %		6.5 %		23.2 %	

Table 10. Results for analysis of TCA-8010 for Lake Winnipeg 99-900 core 3

Sample No	Al[1] %	Sb[2] ppm	Ba[1] ppm	Be[1] ppm	Cd[2] ppm	Ca[1] %	Cs[2] ppm	Cr[1] ppm	Co[1] ppm	Cu[1] ppm	Ga[2] ppm	Fe[1] %	Pb[2] ppm	Mg[1] %	Mn[1] %	Mo[2] ppm
TCA-8010	6.30	2.5	559	1.30	0.05	1.64	1.10	53	8.0	29	12.4	2.28	12.0	0.63	0.04	0.5
TCA-8010	5.98	2.5	560	1.30	-0.05	1.59	1.00	48	8.0	29	12.5	2.26	12.0	0.64	0.04	0.5
TCA-8010	5.55	2.3	561	1.30	0.05	1.52	1.10	48	9.0	29	12.8	2.24	12.0	0.64	0.04	0.4
TCA-8010	5.92	2.5	583	1.40	-0.05	1.58	1.10	52	8.0	29	12.7	2.22	12.0	0.63	0.03	0.5
TCA-8010	5.71	2.4	560	1.40	-0.05	1.57	1.00	52	10.0	30	13.0	2.26	12.0	0.63	0.03	0.5
Mean	5.89	2.4	565	1.34	-0.01	1.58	1.06	51	8.6	29	12.7	2.25	12.0	0.63	0.036	0.5
[3]Mean	6.26	2.5	550	1.04	0.04	1.44	1.13	45	8.7	26	12.2	1.98	13.3	0.62	0.034	0.6
[4]SD	0.25	0.6	86	0.11	0.02	0.04	0.11	3	0.7	4	0.5	0.12	1.5	0.05	0.0017	0.2
No of values	15	15	15	16	11	15	12	16	16	15	11	15	14	16	14	12
% data within 2SD range	60	100	100	0	0	20	100	40	100	100	100	20	100	100	100	100

Sample No	Ni[1] ppm	Nb[2] ppm	P[1] %	K[1] %	Rb[2] ppm	Ag[2] ppm	Na[1] %	Sr[1] ppm	Ta[2] ppm	Tl[2] ppm	Th[2] ppm	Ti[1] %	U[2] ppm	V[1] ppm	Y[2] ppm	Zn[1] ppm
TCA-8010	20.0	6.3	0.05	1.84	55.0	0.07	2.14	296	0.39	0.38	5.4	0.23	1.0	48	15.0	36
TCA-8010	20.0	6.2	0.05	1.84	55.0	0.05	2.14	288	0.44	0.36	4.9	0.26	1.0	49	14.0	35
TCA-8010	20.0	6.0	0.06	1.84	51.0	0.06	2.14	277	0.46	0.35	5.1	0.27	0.9	50	16.0	35
TCA-8010	20.0	5.7	0.05	1.85	54.0	0.07	2.04	286	0.43	0.36	4.9	0.28	0.9	50	15.0	37
TCA-8010	19.0	6.3	0.05	1.83	51.0	0.06	2.11	288	0.42	0.37	5.1	0.26	0.9	50	15.0	35
Mean	19.8	6.1	0.052	1.84	53.2	0.06	2.11	287	0.43	0.36	5.1	0.26	0.9	49	15.0	36
[3]Mean	19.4	5.8	0.050	1.77	52.9	0.23	2.18	289	0.35	0.32	5.8	0.23	1.0	49	13.5	30
[4]SD	2.0	0.4	0.0016	0.04	4.4	0.04	0.09	12	0.12	0.06	0.6	0.01	0.2	3	1.0	4
No of values	16	12	15	15	12	11	16	16	12	12	11	15	12	15	12	16
% data within 2SD range	100	100	80	100	100	0	100	100	100	100	100	20	100	100	80	100

[1]Analysis by ICP-ES

[2]Analysis by ICP-MS

[3]Mean value of TCA-8010 calculated from 8 year record

[4]Standard deviation of values for TCA-8010 calculated from 8 year record

Table 11. Results for analysis of TCA-8010 for Lake Winnipeg 99-900 cores 4 and 8

	As[1]	Hg[2]	Al[3]	Sb[4]	Ba[3]	Be[5]	Bi[5]	Cd[5]	Ca[3]	Ce[4]	Cs[4]	Cr[3]	Co[5]	Cu[3]	Ga[4]	Ge[4]	Fe[3]	La[4]	Pb[5]	Li[4]	Mg[3]
Sample No	ppm	ppb	%	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	%
00IG-0079	3	40	6.34	2.7	600	1.20	0.07	0.04	1.39	45.40	1.10	43	8.8	24	12.2	1.0	1.95	26.0	12.0	10.6	0.60
00IG-0083	3	40	6.39	2.6	620	1.15	0.07	0.06	1.40	47.10	1.05	42	8.2	24	11.6	1.0	1.90	26.5	12.0	9.2	0.61
00IG-0087	3	30	5.60	2.7	450	1.10	0.07	0.02	1.31	46.80	1.05	41	8.6	24	12.2	1.0	1.57	26.5	13.0	9.4	0.55
00IG-0091	2	80	6.47	2.7	470	1.00	0.10	0.06	1.44	46.00	1.20	42	8.8	25	12.5	1.0	1.89	24.0	12.5	9.4	0.61
00IG-0097	2	40	6.70	16.0	1020	1.05	0.10	0.06	1.46	48.10	1.20	47	8.8	25	12.6	1.1	1.99	25.5	12.5	10.2	0.63
00IG-0100	1	40	6.50	2.1	420	0.85	0.09	0.12	1.46	39.70	1.05	42	7.6	26	10.6	0.8	1.91	21.0	10.5	8.0	0.61
00IG-0104	0.5	30	6.67	2.8	770	0.90	0.08	0.02	1.44	46.90	1.10	43	8.2	25	11.8	0.9	1.97	26.5	12.5	9.0	0.63
00IG-0108	2	40	6.41	2.8	650	1.15	0.07	0.02	1.41	47.00	1.10	44	8.2	25	11.8	1.0	1.91	26.5	13.5	8.6	0.61
Mean	2	43	6.39	4.3	625	1.05	0.08	0.05	1.41	45.88	1.11	43	8.4	25	11.9	1.0	1.89	25.3	12.3	9.3	0.61
[6]Mean	n/a	n/a	6.26	2.5	550	1.04	0.09	0.04	1.44	45.60	1.13	45	8.7	26	12.2	1.0	1.98	25.7	13.3	10.1	0.62
[7]SD	n/a	n/a	0.25	0.6	86	0.11	0.02	0.02	0.04	2.80	0.11	3	0.7	4	0.5	0.1	0.12	1.8	1.5	1.6	0.05
No of values	n/a	n/a	15	15	15	16	12	11	15	10	12	16	16	15	11	12	15	11	14	12	16
% data within 2SD range			87.5	87.5	75	100	100	87.5	87.5	87.5	100	100	100	100	87.5	100	87.5	87.5	100	100	100

	Mn[3]	Mo[3]	Ni[5]	Nb[4]	P[3]	K[3]	Rb[4]	Ag[5]	Na[3]	Sr[5]	Ta[4]	Te[4]	Tl[4]	Th[4]	Ti[3]	W[5]	U[4]	V[3]	Y[4]	Zn[3]
Sample No	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm
00IG-0079	330	0.4	17.8	5.8	490	1.72	55.8	0.20	2.19	290.0	0.35	0.10	0.28	5.4	0.22	0.4	0.8	47	13.4	26
00IG-0083	340	0.4	16.4	5.6	490	1.72	52.4	0.20	2.21	295.0	0.45	0.10	0.28	6.2	0.23	0.4	1.0	47	13.0	26
00IG-0087	290	0.4	17.8	6.4	500	1.66	54.6	0.25	2.02	278.0	0.40	0.10	0.28	5.4	0.19	0.4	0.8	45	13.1	26
00IG-0091	340	0.8	22.2	6.0	500	1.77	57.4	0.40	2.28	310.0	0.20	0.10	0.36	4.8	0.23	0.6	1.0	47	13.9	28
00IG-0097	345	0.8	21.8	6.2	520	1.79	60.0	0.30	2.31	312.0	0.15	0.10	0.40	5.0	0.24	0.4	1.0	49	14.1	26
00IG-0100	340	0.4	19.0	5.0	500	1.79	51.0	0.25	2.31	268.0	0.15	0.10	0.26	4.0	0.23	0.4	0.8	49	11.8	28
00IG-0104	350	0.4	16.8	5.6	510	1.78	54.0	0.25	2.30	300.0	0.40	0.10	0.28	6.0	0.23	0.4	1.0	48	13.0	26
00IG-0108	335	0.4	17.0	5.8	510	1.74	53.4	0.25	2.23	290.0	0.45	0.05	0.30	5.6	0.24	0.5	1.0	48	13.4	26
Mean	334	0.5	18.6	5.8	503	1.75	54.8	0.26	2.23	292.9	0.32	0.09	0.31	5.3	0.23	0.4	0.9	48	13.2	27
[6]Mean	339	0.6	19.4	5.8	504	1.77	52.9	0.23	2.18	289.0	0.35	n/a	0.32	5.8	0.23	0.4	1.0	49	13.5	30
[7]SD	17	0.2	2.0	0.4	16	0.04	4.4	0.04	0.09	12.0	0.12	n/a	0.06	0.6	0.01	0.1	0.2	3	1.0	4
No of values	14	12	16	12	15	15	12	11	16	16	12	n/a	12	11	15	11	12	15	12	16
% data within 2SD range	87.5	100	100	100	100	87.5	100	87.5	100	100	100		100	87.5	87.5	100	100	100	100	100

[1]Analysis by AAS-Hydride/EDL with aqua regia decomposition, [2]Analysis by CV-AAS with aqua regia decomposition,
[3]Analysis by ICP-ES with HF-HNO3-HClO4 (near total) decomposition, [4]Analysis by ICP-MS with HF-HNO3-HClO4 (near total) decomposition,
[5]Analysis by ICP-ES/ICP-MS with HF-HNO3-HClO4 (near total) decomposition, [6]Mean value of TCA-8010 calculated from 8 year record,
[7]Standard deviation of values for TCA-8010 calculated from 8 year record.

Table 12. Corrected elemental analysis results for Lake Winnipeg 99-900 core 3

Depth	Al	Sb	Ba	Be	Cd	Ca	Cs	Cr	Co	Cu	Ga	Fe	Pb	Mn	Mg	Mo	Ni
cm	%	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	%	ppm	%	%	ppm	ppm
0-1	8.86	0.9	625	2.40	0.63	1.21	7.53	117	19.6	38	22.0	5.10	29.0	0.12	1.61	0.9	59.0
1-2	9.02	0.9	635	2.40	0.58	1.22	7.53	150	19.5	37	23.0	5.25	27.0	0.12	1.64	0.9	59.0
2-3	8.86	0.9	607	2.40	0.55	1.22	7.33	121	19.4	35	22.0	5.08	27.0	0.10	1.64	0.8	56.0
3-4	8.92	0.9	603	2.40	0.56	1.28	7.33	119	18.3	36	22.0	5.09	27.0	0.10	1.67	0.8	57.0
4-5	9.08	1.0	627	2.40	0.53	1.24	7.09	119	20.2	37	22.0	5.16	28.0	0.12	1.64	0.9	60.0
5-6	8.92	0.9	624	2.40	0.64	1.24	7.49	135	19.1	36	23.0	5.14	27.0	0.12	1.64	0.9	58.0
6-7	8.92	0.9	638	2.50	0.65	1.22	7.29	110	20.0	38	23.0	5.16	28.0	0.12	1.63	0.8	59.0
7-8	8.92	0.9	633	2.50	0.60	1.19	7.19	104	20.9	38	22.0	5.24	27.0	0.13	1.61	0.8	58.0
8-9	8.92	0.9	620	2.40	0.57	1.17	7.29	116	19.8	35	23.0	5.18	26.0	0.12	1.59	0.8	57.0
9-10	8.96	0.9	638	2.50	0.59	1.17	7.29	124	19.7	36	23.0	5.06	26.0	0.12	1.60	0.7	60.0
10-11	9.07	0.8	634	2.50	0.56	1.19	7.79	121	19.7	40	23.0	5.15	26.0	0.13	1.62	0.8	60.0
11-12	9.08	0.9	630	2.50	0.55	1.17	7.89	119	19.6	36	23.0	5.11	27.0	0.12	1.61	0.9	61.0
12-13	9.03	0.9	644	2.50	0.65	1.14	7.39	120	20.5	38	22.0	5.14	26.0	0.12	1.61	1.0	61.0
13-14	9.03	0.9	633	2.50	0.60	1.13	7.39	123	22.4	35	23.0	5.18	26.0	0.12	1.59	1.0	61.0
14-15	8.97	0.8	662	2.50	0.70	1.11	7.53	124	21.6	37	23.0	5.24	24.0	0.12	1.57	1.0	61.0
15-16	9.07	0.8	649	2.50	0.56	1.10	7.43	149	21.5	34	23.0	5.29	23.0	0.12	1.59	0.8	60.0
16-17	9.07	0.7	648	2.40	0.54	1.08	7.43	118	20.4	36	22.0	5.25	23.0	0.12	1.58	0.8	59.0
17-18	9.13	0.8	660	2.50	0.56	1.12	7.43	127	20.3	36	22.0	5.24	23.0	0.12	1.61	0.9	60.0
18-19	9.13	0.8	647	2.50	0.43	1.15	7.19	118	21.2	35	22.0	5.06	23.0	0.10	1.62	0.9	61.0
19-20	8.97	0.7	659	2.50	0.62	1.15	7.59	115	22.1	36	23.0	5.29	22.0	0.15	1.61	1.0	62.0
20-21	9.03	0.7	673	2.50	0.55	1.14	7.49	108	22.0	36	23.0	5.28	22.0	0.13	1.60	0.9	61.0
21-22	9.03	0.7	658	2.50	0.58	1.14	7.09	104	20.9	34	23.0	5.20	22.0	0.14	1.59	0.9	59.0
22-23	8.92	0.7	659	2.40	0.50	1.11	7.39	123	20.9	32	22.0	5.20	21.0	0.14	1.57	0.8	58.0
23-24	8.91	0.7	669	2.60	0.52	1.11	7.39	127	21.8	33	23.0	5.09	21.0	0.14	1.56	0.8	61.0
24-25	9.01	0.7	656	2.50	0.52	1.16	7.79	116	19.7	35	22.0	5.13	22.0	0.13	1.60	0.7	58.0
25-26	8.92	0.7	659	2.50	0.51	1.11	7.89	122	21.6	37	23.0	5.15	23.0	0.14	1.58	0.8	59.0
26-27	9.08	0.7	662	2.50	0.53	1.11	7.79	120	20.5	32	23.0	5.18	22.0	0.13	1.59	0.8	59.0
27-28	8.97	0.7	645	2.50	0.60	1.12	7.49	121	20.4	38	23.0	5.15	21.0	0.14	1.58	0.7	60.0
28-29	8.97	0.7	667	2.50	0.59	1.14	7.53	111	21.6	33	22.0	5.10	21.0	0.13	1.60	0.9	61.0
29-30	8.97	0.7	644	2.40	0.61	1.15	7.43	158	20.5	33	22.0	5.15	20.0	0.15	1.59	0.9	59.0
30-31	9.07	0.7	654	2.40	0.56	1.15	7.53	116	20.4	33	22.0	5.15	21.0	0.14	1.62	0.9	59.0
31-32	9.08	0.7	659	2.40	0.60	1.17	7.53	114	20.3	32	22.0	5.18	21.0	0.15	1.61	0.9	60.0
32-33	8.97	0.7	657	2.40	0.45	1.15	7.53	157	21.2	34	23.0	5.02	21.0	0.12	1.60	1.0	60.0
33-34	8.97	0.7	657	2.50	0.60	1.13	7.59	134	21.1	34	23.0	5.21	20.0	0.14	1.59	0.9	60.0

Table 12 continued

Depth	Al	Sb	Ba	Be	Cd	Ca	Cs	Cr	Co	Cu	Ga	Fe	Pb	Mn	Mg	Mo	Ni
cm	%	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	%	ppm	%	%	ppm	ppm
34-35	9.08	0.7	659	2.50	0.56	1.10	7.49	129	22.1	33	23.0	5.18	20.0	0.15	1.58	0.9	61.0
35-36	8.97	0.7	649	2.50	0.47	1.10	7.39	116	21.0	31	23.0	5.08	21.0	0.14	1.58	0.9	60.0
36-37	9.03	0.7	648	2.50	0.48	1.13	7.69	125	20.9	32	23.0	5.11	20.0	0.13	1.61	0.8	59.0
37-38	8.76	0.7	623	2.40	0.51	1.10	7.49	120	20.8	32	23.0	4.98	20.0	0.14	1.55	0.8	58.0
38-39	9.07	0.6	656	2.50	0.47	1.13	7.59	118	19.7	35	23.0	5.10	20.0	0.13	1.59	0.8	61.0
39-40	8.97	0.7	662	2.50	0.46	1.09	7.69	116	19.6	35	22.0	5.11	21.0	0.15	1.58	1.5	59.0
40-41	9.13	0.7	672	2.50	0.54	1.09	7.79	120	18.5	33	23.0	5.22	22.0	0.15	1.59	0.8	58.0
41-42	9.03	0.7	661	2.50	0.53	1.11	7.49	128	19.4	35	22.0	5.07	21.0	0.14	1.59	0.8	58.0
42-43	9.08	0.7	675	2.50	0.52	1.10	7.53	113	20.6	33	22.0	5.14	22.0	0.14	1.59	0.9	61.0
43-44	9.18	0.7	682	2.50	0.50	1.10	7.93	117	20.5	33	23.0	5.29	21.0	0.13	1.64	0.8	61.0
44-45	9.23	0.7	662	2.50	0.56	1.09	7.63	142	20.4	34	23.0	5.16	21.0	0.13	1.60	0.8	60.0
45-46	9.08	0.7	679	2.50	0.55	1.13	7.43	121	21.3	34	22.0	5.17	21.0	0.14	1.61	0.9	61.0
46-47	9.08	0.7	666	2.40	0.55	1.12	7.53	142	20.2	32	22.0	5.08	20.0	0.14	1.58	0.9	57.0
47-48	8.92	0.7	671	2.40	0.62	1.24	7.49	111	22.2	32	23.0	5.11	20.0	0.15	1.64	0.9	60.0
48-49	8.92	0.7	672	2.50	0.63	1.24	7.39	126	22.1	33	23.0	5.03	20.0	0.13	1.64	0.9	59.0
49-50	8.97	0.7	692	2.40	0.55	1.23	7.19	103	22.0	35	23.0	5.15	22.0	0.15	1.64	1.0	60.0
50-51	8.87	0.7	665	2.40	0.53	1.23	7.29	126	21.9	31	22.0	5.08	22.0	0.14	1.62	0.9	59.0
51-52	8.71	0.7	662	2.40	0.58	1.19	7.29	113	19.8	33	23.0	5.03	22.0	0.14	1.60	0.8	57.0
52-53	8.86	0.7	678	2.40	0.55	1.19	7.39	116	20.7	36	22.0	5.02	22.0	0.14	1.60	0.8	59.0
53-54	8.81	0.7	662	2.40	0.56	1.14	7.69	116	19.6	35	22.0	5.01	28.0	0.14	1.58	0.7	58.0
54-55	8.97	0.7	683	2.50	0.53	1.12	7.49	119	20.5	34	22.0	5.08	22.0	0.14	1.58	0.8	60.0
55-56	8.87	0.7	669	2.40	0.53	1.09	7.39	118	24.4	33	22.0	5.05	22.0	0.14	1.55	0.8	61.0
56-57	8.92	0.7	697	2.40	0.58	1.08	7.53	113	25.6	34	22.0	5.13	21.0	0.14	1.54	0.9	63.0
57-58	9.02	0.7	686	2.50	0.56	1.09	7.73	108	21.5	33	23.0	5.21	22.0	0.14	1.59	0.8	63.0
58-59	9.02	0.7	665	2.50	0.51	1.05	7.53	157	19.4	33	22.0	5.10	21.0	0.14	1.56	0.7	57.0
59-60	9.08	0.7	688	2.50	0.54	1.11	7.53	110	20.4	33	22.0	5.10	21.0	0.13	1.60	0.7	59.0
60-61	9.13	0.7	678	2.40	0.50	1.10	7.73	123	20.3	33	22.0	5.11	20.0	0.14	1.59	0.8	60.0
61-62	9.08	0.7	676	2.50	0.54	1.08	7.69	116	20.2	34	24.0	5.15	20.0	0.14	1.58	0.8	59.0
62-63	9.13	0.7	676	2.60	0.49	1.09	7.59	119	20.1	34	23.0	5.18	21.0	0.15	1.58	0.8	64.0
63-64	9.08	0.8	672	2.50	0.58	1.11	7.59	101	21.0	35	23.0	5.15	22.0	0.13	1.59	1.0	61.0
64-65	9.03	0.7	670	2.40	0.62	1.10	7.49	141	19.9	33	22.0	5.06	21.0	0.12	1.58	0.8	59.0
65-66	8.87	0.7	666	2.40	0.57	1.13	7.39	124	19.8	31	23.0	5.07	21.0	0.14	1.58	0.8	59.0
66-67	8.91	0.7	670	2.50	0.90	1.17	7.49	116	20.7	35	22.0	4.96	21.0	0.12	1.57	0.7	59.0
67-68	8.76	0.7	667	2.50	0.55	1.14	7.69	116	19.6	35	22.0	4.99	21.0	0.14	1.59	0.7	59.0

Table 12 continued

Depth cm	Al %	Sb ppm	Ba ppm	Be ppm	Cd ppm	Ca %	Cs ppm	Cr ppm	Co ppm	Cu ppm	Ga ppm	Fe %	Pb ppm	Mn %	Mg %	Mo ppm	Ni ppm
68-69	8.97	0.7	673	2.50	0.52	1.19	7.59	117	20.5	32	22.0	5.00	22.0	0.14	1.62	0.7	59.0
69-70	8.97	0.8	673	2.50	0.55	1.21	7.79	118	20.4	34	22.0	5.02	21.0	0.13	1.64	0.8	59.0
70-71	8.86	0.7	662	2.50	0.52	1.17	7.53	113	20.6	33	22.0	4.94	21.0	0.14	1.59	0.9	59.0
71-72	8.92	0.7	672	2.50	0.56	1.14	7.73	111	19.6	33	23.0	5.11	20.0	0.14	1.62	0.7	59.0
72-73	8.92	0.7	661	2.40	0.51	1.15	7.23	138	19.5	34	22.0	5.03	21.0	0.13	1.60	0.7	57.0
73-74	9.03	0.7	678	2.40	0.55	1.18	7.43	113	20.4	33	22.0	5.15	21.0	0.12	1.61	0.7	58.0
74-75	9.24	0.7	692	2.50	0.60	1.14	7.83	110	20.3	34	23.0	5.14	22.0	0.14	1.62	0.8	60.0
75-76	8.92	0.7	672	2.50	0.67	1.11	7.69	103	20.2	34	23.0	5.04	20.0	0.13	1.60	0.8	59.0
76-77	9.03	0.7	679	2.50	0.61	1.09	7.69	123	21.1	33	24.0	5.07	20.0	0.13	1.58	0.8	62.0
77-78	8.97	0.7	681	2.40	0.58	1.11	7.19	100	21.0	35	23.0	5.03	21.0	0.12	1.59	0.9	61.0
78-79	9.03	0.8	682	2.50	0.79	1.10	7.49	108	21.9	35	23.0	5.17	21.0	0.14	1.60	0.9	62.0
79-80	8.97	0.7	677	2.50	0.50	1.07	7.59	134	20.8	33	23.0	5.11	21.0	0.13	1.58	0.9	59.0
80-81	9.23	0.7	701	2.50	0.55	1.07	7.89	122	23.7	34	23.0	5.16	20.0	0.13	1.58	0.9	63.0
81-82	8.91	0.7	694	2.50	0.52	1.06	7.99	122	22.6	31	22.0	5.19	21.0	0.15	1.56	0.9	61.0
82-83	9.13	0.8	688	2.50	0.57	1.07	7.69	118	24.5	33	22.0	5.13	22.0	0.14	1.59	0.9	63.0
83-84	9.08	0.8	689	2.50	0.61	1.09	7.89	119	21.4	35	23.0	5.17	22.0	0.14	1.61	0.9	61.0
84-85	9.03	0.7	684	2.50	0.47	1.12	7.69	133	21.3	33	23.0	5.23	21.0	0.14	1.61	0.7	61.0
85-86	9.02	0.7	691	2.50	0.58	1.12	7.63	109	20.7	35	23.0	5.18	22.0	0.13	1.60	1.0	61.0
86-87	9.08	0.8	696	2.50	0.53	1.09	7.73	115	19.6	34	23.0	5.17	21.0	0.14	1.60	0.7	60.0
87-88	9.07	0.7	676	2.40	0.60	1.09	7.43	133	19.5	35	22.0	5.14	21.0	0.15	1.61	0.8	59.0
88-89	9.13	0.8	677	2.50	0.55	1.08	7.73	121	19.4	34	23.0	5.20	20.0	0.14	1.58	0.8	59.0
89-90	9.24	0.7	685	2.50	0.65	1.13	7.53	110	22.3	35	23.0	5.20	20.0	0.15	1.64	1.0	68.0
90-91	9.24	0.7	695	2.50	0.50	1.11	7.79	114	23.2	34	24.0	5.27	21.0	0.13	1.64	1.1	64.0
91-92	9.13	0.7	699	2.50	0.49	1.11	7.69	125	24.1	35	24.0	5.34	19.0	0.15	1.64	1.1	65.0
92-93	9.08	0.7	687	2.50	0.51	1.13	7.39	106	21.0	35	23.0	5.20	20.0	0.13	1.64	0.9	58.0
93-94	9.03	0.7	678	2.50	0.52	1.08	7.39	115	23.9	33	23.0	5.08	20.0	0.13	1.58	1.1	60.0
94-95	9.08	0.7	679	2.50	0.44	1.06	7.69	129	21.8	34	24.0	5.20	20.0	0.12	1.59	1.0	61.0
95-96	9.23	0.7	697	2.50	0.46	1.09	7.79	122	22.7	34	22.0	5.20	21.0	0.12	1.60	0.8	65.0
96-97	8.91	0.7	687	2.50	0.54	1.12	7.89	118	20.6	36	23.0	5.09	21.0	0.12	1.61	0.8	63.0
97-98	9.18	0.7	697	2.50	0.54	1.09	7.79	118	20.5	33	23.0	5.22	22.0	0.14	1.61	0.8	60.0
98-99	9.08	0.7	689	2.50	0.52	1.11	7.69	119	19.4	34	22.0	5.20	22.0	0.13	1.61	0.7	58.0
99-100	8.97	0.7	683	2.40	0.51	1.17	7.69	118	19.3	32	22.0	5.08	20.0	0.13	1.63	0.7	58.0
100-101	9.13	0.7	704	2.50	0.51	1.15	7.53	110	20.7	35	22.0	5.17	20.0	0.14	1.63	0.7	60.0
101-102	9.08	0.7	711	2.50	0.52	1.15	7.83	119	20.6	34	23.0	5.12	20.0	0.14	1.63	0.8	61.0

Table 12 continued

Depth cm	Al %	Sb ppm	Ba ppm	Be ppm	Cd ppm	Ca %	Cs ppm	Cr ppm	Co ppm	Cu ppm	Ga ppm	Fe %	Pb ppm	Mn %	Mg %	Mo ppm	Ni ppm
102-103	9.02	0.7	681	2.40	0.52	1.11	7.53	137	20.5	33	22.0	5.10	21.0	0.15	1.60	0.8	59.0
103-104	8.97	0.7	677	2.40	0.50	1.13	7.33	124	20.4	34	22.0	5.13	21.0	0.14	1.58	0.8	58.0
104-105	9.08	0.7	688	2.40	0.55	1.17	7.53	109	21.3	34	22.0	5.19	20.0	0.14	1.64	0.8	59.0
105-106	9.18	0.7	691	2.50	0.60	1.14	7.79	114	20.2	35	24.0	5.19	21.0	0.14	1.64	0.8	60.0
106-107	9.03	0.8	685	2.50	0.51	1.09	7.89	120	21.1	34	23.0	5.20	20.0	0.15	1.60	0.9	62.0
107-108	9.08	0.7	676	2.50	0.52	1.04	7.59	115	22.0	36	23.0	5.16	20.0	0.14	1.56	0.9	62.0
108-109	8.97	0.8	673	2.50	0.52	1.02	7.49	113	21.9	34	23.0	5.15	21.0	0.15	1.55	1.6	61.0
109-110	9.08	0.8	676	2.50	0.53	1.04	7.59	119	21.8	34	23.0	5.23	21.0	0.13	1.57	0.9	61.0
110-111	9.07	0.7	685	2.50	0.57	1.06	7.69	119	20.7	36	22.0	5.23	22.0	0.14	1.56	0.7	61.0
111-112	8.86	0.7	683	2.50	0.60	1.04	7.99	115	21.6	36	23.0	5.14	21.0	0.15	1.56	0.7	61.0
112-113	9.13	0.8	686	2.50	0.58	1.09	7.69	118	21.5	34	22.0	5.26	22.0	0.14	1.59	0.8	60.0
113-114	9.08	0.8	675	2.50	0.55	1.08	7.79	120	19.4	32	23.0	5.19	20.0	0.14	1.60	0.8	59.0
114-115	9.08	0.7	676	2.50	0.52	1.11	7.59	137	21.3	33	22.0	5.17	20.0	0.13	1.61	0.9	61.0
115-116	9.08	0.7	688	2.50	0.56	1.11	7.63	107	22.7	34	23.0	5.15	21.0	0.12	1.62	1.0	62.0
116-117	9.13	0.7	691	2.50	0.51	1.05	7.83	113	20.6	34	23.0	5.15	20.0	0.14	1.59	0.8	60.0
117-118	9.07	0.8	665	2.40	0.50	1.08	7.73	109	19.5	32	23.0	5.11	20.0	0.13	1.60	0.7	57.0
118-119	8.97	0.8	649	2.40	0.48	1.07	7.53	117	18.4	33	22.0	5.06	20.0	0.13	1.55	0.7	57.0
119-120	9.18	0.8	679	2.50	0.49	1.14	7.73	122	18.3	34	22.0	5.19	20.0	0.14	1.65	0.7	59.0
120-121	9.03	0.8	666	2.50	0.54	1.11	7.79	134	23.2	34	23.0	5.27	20.0	0.15	1.60	1.5	71.0
121-122	9.13	0.7	678	2.50	0.56	1.14	7.79	107	21.1	35	24.0	5.15	21.0	0.12	1.64	0.7	61.0
122-123	9.18	0.8	685	2.50	0.57	1.16	7.79	104	20.0	35	24.0	5.15	20.0	0.13	1.65	0.8	60.0
123-124	8.97	0.8	656	2.50	0.53	1.17	7.39	124	21.9	34	22.0	5.10	20.0	0.14	1.63	0.8	60.0
124-125	9.08	0.8	670	2.50	0.50	1.22	7.49	125	21.8	36	22.0	5.20	20.0	0.12	1.68	0.8	63.0
125-126	9.12	0.8	682	2.50	0.51	1.19	7.39	124	20.7	33	23.0	5.13	21.0	0.13	1.66	0.8	62.0
126-127	9.17	0.8	689	2.50	0.52	1.17	7.89	119	20.6	36	23.0	5.27	22.0	0.13	1.65	0.7	62.0
127-128	9.08	0.7	696	2.50	0.66	1.14	7.79	118	19.5	36	22.0	5.21	22.0	0.14	1.63	0.7	60.0
128-129	9.18	0.7	714	2.50	0.56	1.13	7.49	119	20.4	36	23.0	5.18	22.0	0.12	1.64	0.9	62.0
129-130	9.03	0.7	695	2.50	0.49	1.11	7.49	125	21.3	35	22.0	5.25	21.0	0.14	1.61	0.9	62.0
130-131	9.13	0.7	707	2.50	0.52	1.09	7.63	108	23.7	37	23.0	5.17	22.0	0.12	1.61	0.8	64.0
131-132	9.18	0.8	715	2.50	0.54	1.16	7.83	112	21.6	35	23.0	5.19	21.0	0.14	1.65	0.8	62.0
132-133	9.07	0.7	683	2.40	0.52	1.19	7.53	120	20.5	35	23.0	5.10	21.0	0.14	1.68	0.8	60.0
133-134	9.07	0.7	671	2.40	0.51	1.15	7.53	118	20.4	33	22.0	5.08	19.0	0.14	1.63	0.8	58.0
134-135	9.13	0.7	689	2.40	0.53	1.18	7.73	109	20.3	32	22.0	5.10	20.0	0.14	1.65	0.8	59.0
135-136	9.24	0.7	696	2.50	0.53	1.19	7.39	134	21.2	33	23.0	5.16	19.0	0.14	1.66	0.9	61.0

Table 12 continued

Depth cm	Al %	Sb ppm	Ba ppm	Be ppm	Cd ppm	Ca %	Cs ppm	Cr ppm	Co ppm	Cu ppm	Ga ppm	Fe %	Pb ppm	Mn %	Mg %	Mo ppm	Ni ppm
136-137	9.08	0.7	691	2.50	0.51	1.17	7.69	115	22.1	34	23.0	5.22	20.0	0.14	1.65	0.8	63.0
137-138	9.08	0.7	686	2.50	0.50	1.19	7.49	107	21.0	34	24.0	5.24	20.0	0.15	1.67	0.8	61.0
138-139	9.18	0.7	688	2.50	0.49	1.24	7.49	114	19.9	36	23.0	5.24	20.0	0.13	1.71	0.8	59.0
139-140	9.03	0.7	667	2.50	0.48	1.34	7.39	124	18.8	33	23.0	5.17	20.0	0.13	1.74	0.8	58.0
140-141	9.17	0.8	679	2.50	0.56	1.36	7.39	122	19.7	32	23.0	5.08	20.0	0.12	1.75	0.8	59.0
141-142	9.17	0.7	671	2.50	0.49	1.30	7.69	119	21.6	37	23.0	5.14	20.0	0.12	1.71	0.7	62.0
142-143	8.81	0.7	681	2.40	0.50	1.24	7.39	113	21.5	33	21.0	5.08	21.0	0.12	1.67	0.8	61.0
143-144	9.18	0.7	689	2.50	0.49	1.19	7.69	116	19.5	33	23.0	5.27	20.0	0.13	1.68	0.8	60.0
144-145	9.03	0.7	673	2.40	0.47	1.20	7.59	125	20.4	32	22.0	5.20	20.0	0.14	1.65	0.7	59.0

Table 12 continued

Depth cm	Nb ppm	P %	K %	Rb ppm	Ag ppm	Na %	Sr ppm	Ta ppm	Tl ppm	Th ppm	Ti %	U ppm	V ppm	Y ppm	Zn ppm
0-1	14.0	0.10	2.09	131.0	0.27	0.55	130.0	0.93	0.92	13.5	0.39	3.2	200	22.4	159
1-2	13.0	0.10	2.10	131.0	0.28	0.56	130.0	0.94	0.90	13.5	0.37	3.1	198	22.4	159
2-3	13.0	0.09	2.05	128.0	0.26	0.54	125.0	0.95	0.93	13.5	0.37	3.2	198	21.4	155
3-4	13.0	0.09	2.12	127.0	0.25	0.54	127.0	0.95	0.91	12.5	0.38	3.2	201	21.4	169
4-5	13.0	0.09	2.15	129.0	0.30	0.55	131.0	0.93	0.93	13.5	0.39	3.2	202	21.8	155
5-6	14.0	0.08	2.16	136.0	0.27	0.56	130.0	0.89	0.91	12.7	0.38	3.3	202	22.8	153
6-7	14.0	0.08	2.13	137.0	0.29	0.55	131.0	0.95	0.92	13.7	0.40	3.4	205	22.8	156
7-8	13.0	0.08	2.13	128.0	0.28	0.55	131.0	0.97	0.89	12.7	0.40	3.2	202	21.8	154
8-9	14.0	0.08	2.12	133.0	0.24	0.56	129.0	0.98	0.93	13.7	0.39	3.2	199	21.8	152
9-10	14.0	0.08	2.11	136.0	0.19	0.57	129.0	0.98	0.92	13.7	0.39	3.3	203	21.8	157
10-11	14.0	0.08	2.13	135.0	0.25	0.56	131.0	0.93	0.95	13.7	0.40	3.3	205	22.8	158
11-12	14.0	0.07	2.13	136.0	0.27	0.55	132.0	0.90	0.94	13.7	0.38	3.4	204	22.8	155
12-13	14.0	0.08	2.13	133.0	0.24	0.55	132.0	0.94	0.97	13.7	0.40	3.5	204	23.8	153
13-14	14.0	0.08	2.13	130.0	0.24	0.55	131.0	0.96	0.94	13.7	0.39	3.2	204	21.8	151
14-15	14.0	0.08	2.12	133.0	0.20	0.56	129.0	0.97	0.97	13.5	0.39	3.1	202	23.4	154
15-16	13.0	0.07	2.14	133.0	0.18	0.57	129.0	0.94	0.91	13.5	0.39	3.1	199	22.4	150
16-17	14.0	0.08	2.12	132.0	0.17	0.57	130.0	0.93	0.92	13.5	0.39	3.0	199	22.4	148
17-18	14.0	0.07	2.15	130.0	0.17	0.56	130.0	0.97	0.94	13.5	0.40	3.0	204	22.4	146
18-19	13.0	0.07	2.16	130.0	0.18	0.56	130.0	0.95	0.94	13.5	0.38	3.1	201	22.4	146
19-20	14.0	0.07	2.13	133.0	0.16	0.54	128.0	0.97	0.92	13.7	0.40	3.0	204	21.8	145
20-21	14.0	0.07	2.15	134.0	0.17	0.56	131.0	0.97	0.94	13.7	0.40	3.0	204	21.8	147
21-22	14.0	0.08	2.16	130.0	0.17	0.56	131.0	0.99	0.94	12.7	0.41	3.0	202	22.8	145
22-23	13.0	0.07	2.13	132.0	0.17	0.56	129.0	0.94	0.95	13.7	0.38	2.9	199	21.8	142
23-24	14.0	0.07	2.10	132.0	0.15	0.56	128.0	0.99	0.93	12.7	0.40	2.9	204	21.8	150
24-25	14.0	0.07	2.13	134.0	0.17	0.56	130.0	0.96	0.96	13.7	0.40	2.8	203	21.8	147
25-26	14.0	0.07	2.12	134.0	0.16	0.55	131.0	0.97	0.93	13.7	0.38	2.9	204	22.8	147
26-27	14.0	0.07	2.13	136.0	0.16	0.55	133.0	0.96	0.97	13.7	0.40	3.1	208	23.8	147
27-28	14.0	0.07	2.13	126.0	0.19	0.55	132.0	0.98	0.93	12.7	0.40	2.8	206	21.8	145
28-29	14.0	0.07	2.13	130.0	0.16	0.56	132.0	0.95	0.97	12.5	0.41	2.9	205	22.4	147
29-30	13.0	0.07	2.10	128.0	0.15	0.56	129.0	0.94	0.94	13.5	0.38	2.8	201	22.4	143
30-31	14.0	0.07	2.12	130.0	0.14	0.56	130.0	0.94	0.95	13.5	0.38	2.8	204	22.4	145
31-32	14.0	0.07	2.16	126.0	0.16	0.57	132.0	0.94	0.94	12.5	0.38	2.7	205	22.4	146
32-33	14.0	0.07	2.15	133.0	0.16	0.59	134.0	1.01	0.94	13.5	0.41	2.8	203	22.4	144
33-34	15.0	0.07	2.17	135.0	0.16	0.56	132.0	0.98	0.93	12.7	0.41	2.9	208	23.8	142

Table 12 continued

Depth cm	Nb ppm	P %	K %	Rb ppm	Ag ppm	Na %	Sr ppm	Ta ppm	Tl ppm	Th ppm	Ti %	U ppm	V ppm	Y ppm	Zn ppm
34-35	14.0	0.07	2.17	136.0	0.16	0.56	131.0	0.90	0.93	12.7	0.38	2.8	208	22.8	145
35-36	14.0	0.07	2.12	129.0	0.17	0.54	129.0	1.00	0.98	12.7	0.39	2.8	208	22.8	146
36-37	14.0	0.07	2.13	134.0	0.16	0.55	129.0	0.95	0.97	13.7	0.38	2.8	208	22.8	143
37-38	14.0	0.07	2.08	136.0	0.15	0.56	125.0	0.97	0.95	12.7	0.38	2.7	201	21.8	141
38-39	14.0	0.07	2.16	133.0	0.16	0.56	131.0	0.97	0.93	12.7	0.40	2.7	208	22.8	144
39-40	14.0	0.07	2.14	134.0	0.14	0.55	132.0	0.95	0.93	12.7	0.39	2.7	208	22.8	147
40-41	14.0	0.07	2.16	130.0	0.16	0.55	134.0	0.97	0.97	13.7	0.39	2.9	213	22.8	147
41-42	14.0	0.07	2.13	128.0	0.19	0.55	132.0	0.94	0.96	12.7	0.38	2.8	210	21.8	145
42-43	14.0	0.07	2.16	133.0	0.14	0.56	133.0	1.01	0.98	13.5	0.41	2.9	208	23.4	148
43-44	14.0	0.07	2.20	136.0	0.20	0.58	133.0	0.98	0.96	13.5	0.39	2.8	212	22.4	150
44-45	14.0	0.07	2.15	136.0	0.17	0.59	133.0	0.95	0.94	13.5	0.39	2.8	206	23.4	146
45-46	14.0	0.07	2.16	129.0	0.15	0.58	133.0	0.97	0.95	13.5	0.40	2.8	209	22.4	144
46-47	14.0	0.07	2.15	130.0	0.15	0.56	131.0	0.94	0.91	12.5	0.40	2.7	205	22.4	141
47-48	14.0	0.07	2.17	133.0	0.14	0.59	134.0	0.96	0.92	12.7	0.40	2.8	203	22.8	142
48-49	14.0	0.07	2.15	135.0	0.16	0.59	134.0	0.91	0.92	12.7	0.39	2.8	204	22.8	144
49-50	14.0	0.07	2.17	128.0	0.18	0.59	136.0	0.98	0.97	13.7	0.41	2.9	205	22.8	142
50-51	14.0	0.07	2.13	124.0	0.16	0.59	134.0	0.97	0.94	13.7	0.38	2.8	198	21.8	139
51-52	14.0	0.07	2.12	133.0	0.16	0.59	134.0	0.99	0.94	13.7	0.40	2.8	198	22.8	139
52-53	14.0	0.07	2.13	133.0	0.17	0.60	136.0	0.97	0.95	13.7	0.41	2.9	202	22.8	145
53-54	14.0	0.07	2.12	133.0	0.16	0.58	134.0	0.96	0.97	13.7	0.38	2.8	198	23.8	143
54-55	14.0	0.07	2.14	128.0	0.18	0.59	138.0	0.98	0.96	12.7	0.41	2.9	204	23.8	146
55-56	14.0	0.07	2.12	125.0	0.18	0.59	137.0	0.98	0.93	12.7	0.39	2.9	201	21.8	143
56-57	14.0	0.08	2.15	129.0	0.26	0.60	137.0	0.99	0.98	13.5	0.41	2.8	203	22.4	146
57-58	14.0	0.07	2.18	133.0	0.44	0.60	136.0	0.98	0.96	13.5	0.41	2.9	206	23.4	146
58-59	14.0	0.07	2.12	131.0	0.17	0.59	129.0	0.97	0.93	13.5	0.39	2.7	203	22.4	144
59-60	14.0	0.07	2.19	130.0	0.17	0.58	134.0	0.98	0.93	13.5	0.41	2.8	209	22.4	143
60-61	14.0	0.07	2.19	129.0	0.16	0.57	132.0	1.00	0.95	13.5	0.41	2.8	208	22.4	144
61-62	14.0	0.07	2.19	138.0	0.15	0.56	132.0	0.92	0.91	12.7	0.40	2.7	210	23.8	146
62-63	14.0	0.07	2.17	136.0	0.16	0.56	131.0	0.98	0.98	13.7	0.39	2.9	209	22.8	148
63-64	14.0	0.07	2.17	132.0	0.16	0.56	132.0	1.00	1.00	13.7	0.41	3.1	212	23.8	147
64-65	14.0	0.07	2.15	129.0	0.17	0.58	133.0	0.94	0.96	13.7	0.38	2.9	205	22.8	142
65-66	14.0	0.07	2.13	134.0	0.14	0.57	132.0	0.98	0.91	12.7	0.40	2.7	205	21.8	141
66-67	13.0	0.07	2.13	128.0	0.17	0.59	135.0	0.94	0.92	13.7	0.39	2.7	204	21.8	145
67-68	14.0	0.07	2.12	130.0	0.16	0.57	131.0	0.98	0.97	12.7	0.40	2.8	208	22.8	146

Table 12 continued

Depth	Nb	P	K	Rb	Ag	Na	Sr	Ta	Tl	Th	Ti	U	V	Y	Zn
cm	ppm	%	%	ppm	ppm	%	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm
68-69	14.0	0.07	2.13	130.0	0.18	0.55	133.0	0.98	0.95	12.7	0.40	2.9	210	22.8	145
69-70	14.0	0.07	2.13	133.0	0.16	0.56	133.0	0.98	0.95	12.7	0.39	2.9	211	23.8	144
70-71	14.0	0.07	2.13	127.0	0.16	0.60	131.0	0.99	0.96	12.5	0.39	2.9	201	23.4	144
71-72	14.0	0.07	2.15	135.0	0.19	0.59	133.0	0.96	0.94	13.5	0.39	2.8	205	23.4	145
72-73	13.0	0.07	2.10	126.0	0.14	0.58	130.0	0.94	0.95	13.5	0.38	2.7	200	22.4	143
73-74	14.0	0.07	2.16	128.0	0.15	0.59	134.0	0.95	0.97	13.5	0.39	2.8	205	22.4	146
74-75	14.0	0.07	2.21	130.0	0.16	0.59	136.0	1.01	0.95	13.5	0.41	2.9	211	22.4	143
75-76	14.0	0.07	2.17	133.0	0.14	0.57	131.0	0.97	0.93	13.7	0.41	2.9	208	22.8	143
76-77	14.0	0.07	2.17	137.0	0.17	0.58	132.0	0.95	0.95	12.7	0.39	2.9	206	22.8	145
77-78	15.0	0.07	2.17	130.0	0.15	0.58	134.0	1.00	0.96	13.7	0.41	3.0	207	23.8	143
78-79	16.0	0.07	2.17	132.0	0.23	0.58	134.0	0.98	0.93	12.7	0.41	2.9	207	23.8	144
79-80	15.0	0.07	2.14	134.0	0.13	0.58	132.0	0.99	0.94	13.7	0.41	2.9	203	21.8	141
80-81	14.0	0.07	2.19	135.0	0.17	0.59	136.0	0.94	0.95	12.7	0.40	2.8	207	21.8	147
81-82	14.0	0.07	2.17	135.0	0.16	0.58	135.0	0.98	0.97	13.7	0.40	2.9	202	22.8	143
82-83	15.0	0.08	2.16	133.0	0.16	0.57	135.0	0.96	0.96	13.7	0.40	2.9	209	23.8	144
83-84	14.0	0.07	2.17	129.0	0.17	0.57	135.0	0.98	0.97	13.7	0.40	3.0	209	22.8	144
84-85	14.0	0.07	2.16	129.0	0.16	0.57	134.0	0.97	0.93	13.7	0.39	2.8	207	21.8	143
85-86	14.0	0.07	2.18	131.0	0.19	0.59	134.0	0.99	0.97	13.5	0.41	3.0	203	23.4	146
86-87	15.0	0.07	2.14	135.0	0.15	0.57	131.0	1.02	0.97	13.5	0.41	2.9	206	23.4	147
87-88	14.0	0.07	2.14	131.0	0.16	0.58	130.0	0.96	0.94	13.5	0.39	3.0	199	22.4	144
88-89	14.0	0.07	2.13	134.0	0.15	0.58	130.0	0.92	0.97	13.5	0.37	2.8	205	22.4	144
89-90	14.0	0.07	2.20	130.0	0.19	0.57	132.0	0.95	0.94	12.5	0.40	2.9	212	21.4	146
90-91	14.0	0.07	2.22	138.0	0.14	0.58	133.0	1.01	0.97	13.7	0.41	3.0	210	22.8	144
91-92	14.0	0.07	2.22	140.0	0.14	0.59	133.0	0.94	0.94	13.7	0.39	2.9	209	21.8	146
92-93	14.0	0.07	2.18	132.0	0.16	0.56	131.0	0.98	0.94	13.7	0.41	2.9	207	21.8	143
93-94	15.0	0.07	1.98	120.0	0.23	0.56	130.0	0.96	0.96	12.7	0.39	2.9	204	22.8	143
94-95	14.0	0.07	2.17	140.0	0.16	0.56	130.0	0.98	0.97	13.7	0.39	2.7	206	22.8	143
95-96	14.0	0.07	2.19	132.0	0.17	0.58	134.0	0.94	0.97	13.7	0.40	2.8	210	22.8	147
96-97	14.0	0.07	2.18	134.0	0.17	0.58	134.0	0.96	0.92	13.7	0.40	2.8	207	22.8	146
97-98	15.0	0.07	2.18	136.0	0.16	0.58	136.0	0.98	0.97	13.7	0.41	3.0	209	24.8	145
98-99	14.0	0.07	2.17	131.0	0.16	0.58	136.0	0.98	0.95	13.7	0.39	2.9	206	22.8	143
99-100	14.0	0.07	2.15	130.0	0.19	0.57	133.0	0.97	0.94	12.7	0.39	2.7	205	21.8	142
100-101	14.0	0.07	2.21	131.0	0.17	0.59	138.0	0.95	0.97	13.5	0.41	2.9	201	22.4	143
101-102	14.0	0.07	2.16	135.0	0.20	0.58	133.0	0.96	0.92	13.5	0.40	2.7	205	23.4	147

Table 12 continued

Depth	Nb	P	K	Rb	Ag	Na	Sr	Ta	Tl	Th	Ti	U	V	Y	Zn
cm	ppm	%	%	ppm	ppm	%	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm
102-103	14.0	0.07	2.12	131.0	0.16	0.58	129.0	0.97	0.93	13.5	0.39	2.9	199	22.4	142
103-104	13.0	0.07	2.12	125.0	0.14	0.59	130.0	0.94	0.94	13.5	0.37	2.8	200	22.4	142
104-105	14.0	0.07	2.16	129.0	0.16	0.58	132.0	0.99	0.94	12.5	0.41	2.8	205	22.4	142
105-106	14.0	0.07	2.20	135.0	0.14	0.56	131.0	1.01	0.95	12.7	0.41	2.9	210	22.8	145
106-107	14.0	0.07	2.17	136.0	0.18	0.55	127.0	0.98	0.96	13.7	0.40	2.9	211	21.8	146
107-108	14.0	0.07	2.15	133.0	0.15	0.53	127.0	0.99	0.96	13.7	0.40	2.9	210	21.8	146
108-109	15.0	0.07	2.12	131.0	0.22	0.53	126.0	1.00	0.95	12.7	0.39	3.0	208	22.8	145
109-110	15.0	0.07	2.16	134.0	0.15	0.56	130.0	0.99	0.95	13.7	0.41	2.9	208	22.8	145
110-111	14.0	0.08	2.15	129.0	0.16	0.56	132.0	0.99	0.92	12.7	0.41	2.9	209	21.8	148
111-112	14.0	0.07	2.14	136.0	0.16	0.55	131.0	0.94	0.92	13.7	0.40	2.9	208	22.8	145
112-113	14.0	0.07	2.14	130.0	0.18	0.55	131.0	0.96	0.94	13.7	0.38	3.0	211	22.8	147
113-114	14.0	0.07	2.14	132.0	0.16	0.54	130.0	0.96	0.95	12.7	0.38	2.9	211	22.8	146
114-115	14.0	0.07	2.14	132.0	0.19	0.54	130.0	0.93	0.93	12.7	0.39	2.7	210	21.8	145
115-116	14.0	0.07	2.20	131.0	0.16	0.57	135.0	1.01	0.97	13.5	0.41	3.1	208	22.4	145
116-117	14.0	0.07	2.15	134.0	0.14	0.54	128.0	1.00	0.99	13.5	0.40	2.9	211	22.4	150
117-118	14.0	0.07	2.11	133.0	0.15	0.54	124.0	0.93	0.93	13.5	0.38	2.9	205	22.4	146
118-119	13.0	0.07	2.07	132.0	0.15	0.53	123.0	0.88	0.96	12.5	0.35	2.7	205	22.4	144
119-120	14.0	0.07	2.19	128.0	0.15	0.54	128.0	0.99	0.94	12.5	0.40	2.8	212	21.4	143
120-121	14.0	0.07	2.16	136.0	0.15	0.53	126.0	0.97	0.91	12.7	0.39	3.0	210	23.8	147
121-122	15.0	0.07	2.17	138.0	0.17	0.54	128.0	0.97	0.97	12.7	0.40	3.0	214	22.8	148
122-123	14.0	0.07	2.18	137.0	0.14	0.54	130.0	0.97	0.92	12.7	0.41	2.8	214	21.8	147
123-124	14.0	0.07	2.12	130.0	0.16	0.54	127.0	0.95	0.90	12.7	0.39	2.7	205	21.8	143
124-125	14.0	0.07	2.17	132.0	0.16	0.57	131.0	0.98	0.93	12.7	0.40	2.8	206	21.8	144
125-126	14.0	0.07	2.16	136.0	0.13	0.56	132.0	0.99	0.95	13.7	0.40	2.9	206	21.8	145
126-127	15.0	0.07	2.19	138.0	0.19	0.55	134.0	0.98	0.95	13.7	0.42	2.9	209	23.8	148
127-128	14.0	0.07	2.16	136.0	0.18	0.59	136.0	0.95	0.94	13.7	0.40	3.0	205	23.8	146
128-129	15.0	0.07	2.21	134.0	0.19	0.60	140.0	0.98	0.97	13.7	0.41	3.2	207	23.8	145
129-130	15.0	0.07	2.17	133.0	0.19	0.58	136.0	0.96	0.94	12.7	0.40	2.8	203	22.8	144
130-131	14.0	0.07	2.21	128.0	0.28	0.60	138.0	1.02	0.97	13.5	0.42	3.1	202	22.4	145
131-132	15.0	0.07	2.20	137.0	0.15	0.59	135.0	1.00	0.98	13.5	0.42	2.9	209	23.4	149
132-133	13.0	0.07	2.14	131.0	0.14	0.58	129.0	0.95	0.95	13.5	0.38	2.9	200	22.4	145
133-134	13.0	0.07	2.13	131.0	0.15	0.59	129.0	0.91	0.95	12.5	0.36	2.8	200	22.4	143
134-135	14.0	0.07	2.20	131.0	0.14	0.59	132.0	0.98	0.93	12.5	0.41	2.7	203	22.4	140
135-136	13.0	0.07	2.20	132.0	0.17	0.58	134.0	0.94	0.91	12.5	0.40	2.7	205	21.8	142

Table 12 continued

Depth cm	**Nb** ppm	**P** %	**K** %	**Rb** ppm	**Ag** ppm	**Na** %	**Sr** ppm	**Ta** ppm	**Tl** ppm	**Th** ppm	**Ti** %	**U** ppm	**V** ppm	**Y** ppm	**Zn** ppm
136-137	14.0	0.07	2.19	137.0	0.16	0.59	133.0	0.93	0.95	13.7	0.40	2.9	204	22.8	142
137-138	14.0	0.07	2.18	139.0	0.15	0.57	133.0	0.96	0.94	13.7	0.40	2.9	208	21.8	144
138-139	14.0	0.07	2.21	133.0	0.17	0.58	135.0	0.97	0.93	12.7	0.41	2.9	208	22.8	144
139-140	14.0	0.07	2.15	135.0	0.17	0.56	130.0	0.96	0.94	12.7	0.39	3.0	204	21.8	141
140-141	14.0	0.07	2.17	134.0	0.12	0.58	133.0	0.96	0.95	12.7	0.40	2.8	205	21.8	142
141-142	14.0	0.07	2.17	135.0	0.16	0.57	132.0	0.93	0.95	13.7	0.40	2.7	205	22.8	146
142-143	13.0	0.07	2.13	129.0	0.17	0.57	132.0	0.94	0.97	13.7	0.38	2.9	200	22.8	142
143-144	15.0	0.08	2.19	138.0	0.16	0.58	137.0	0.98	0.96	13.7	0.40	2.9	204	22.8	143
144-145	14.0	0.08	2.16	131.0	0.19	0.58	135.0	0.98	0.95	13.7	0.40	2.7	199	21.8	143

Table 13. Uncorrected elemental analysis results for Lake Winnipeg 99-900 core 3 additional elements

Depth	Ce	Dy	Er	Eu	Gd	Ho	La	Lu	Nd	Pr	Sc	Sm	Tb	Tm	Yb	Bi	Hf	In	Sn	Te	Zr
cm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Method	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-ES	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS
Detection Limit	0.10	0.02	0.02	0.02	0.02	0.02	0.05	0.02	0.05	0.02	0.50	0.02	0.02	0.02	0.02	0.05	0.02	0.02	0.05	0.10	0.50
0-1	79.0	3.90	1.90	1.20	4.80	0.75	39.00	0.32	33.00	9.10	17.0	6.00	0.67	0.31	2.00	0.44	3.20	0.07	2.60	0.1	113.0
1-2	78.0	3.80	2.00	1.20	4.90	0.77	39.00	0.31	33.00	8.80	16.0	6.10	0.67	0.31	2.00	0.41	3.10	0.07	2.50	0.1	113.0
2-3	74.0	3.80	1.90	1.20	4.80	0.76	37.00	0.31	31.00	8.50	16.0	6.10	0.68	0.32	2.10	0.40	3.30	0.07	2.60	0.1	112.0
3-4	76.0	3.80	1.90	1.20	4.80	0.76	38.00	0.31	31.00	8.60	16.0	6.00	0.68	0.30	2.00	0.43	3.20	0.07	2.60	0.1	108.0
4-5	76.0	3.80	1.90	1.20	4.80	0.79	40.00	0.31	33.00	9.00	17.0	6.20	0.70	0.32	2.10	0.40	3.20	0.07	2.70	0.1	112.0
5-6	81.0	3.90	2.00	1.20	4.80	0.76	39.00	0.33	34.00	9.40	16.0	6.00	0.68	0.31	2.00	0.41	3.20	0.07	2.60	0.1	115.0
6-7	78.0	3.90	2.10	1.20	4.90	0.76	39.00	0.34	33.00	9.40	17.0	6.30	0.71	0.32	2.10	0.46	3.40	0.08	2.90	0.1	115.0
7-8	77.0	3.90	2.00	1.20	4.80	0.77	38.00	0.32	33.00	9.00	17.0	6.00	0.72	0.32	2.10	0.43	3.20	0.07	2.60	0.1	113.0
8-9	79.0	4.00	2.00	1.20	5.00	0.80	41.00	0.33	33.00	9.40	16.0	6.00	0.73	0.31	2.10	0.42	3.30	0.08	2.90	0.1	115.0
9-10	81.0	3.70	2.00	1.20	5.00	0.78	42.00	0.33	33.00	9.40	17.0	6.30	0.72	0.32	2.10	0.42	3.20	0.07	2.80	0.1	115.0
10-11	79.0	3.90	2.00	1.20	4.90	0.73	40.00	0.34	34.00	9.60	17.0	6.10	0.69	0.32	2.10	0.43	3.20	0.08	2.70	0.1	115.0
11-12	80.0	4.00	2.00	1.20	4.70	0.75	41.00	0.33	34.00	9.70	17.0	6.00	0.67	0.32	2.10	0.43	3.30	0.08	2.80	0.1	118.0
12-13	80.0	4.10	2.00	1.20	4.70	0.80	41.00	0.33	35.00	9.90	17.0	6.10	0.72	0.34	2.10	0.43	3.40	0.08	3.00	0.1	116.0
13-14	81.0	3.90	2.00	1.20	4.80	0.78	40.00	0.32	35.00	9.40	17.0	6.20	0.72	0.31	2.10	0.45	3.40	0.08	2.60	0.1	119.0
14-15	79.0	3.90	2.00	1.20	4.90	0.78	40.00	0.33	35.00	9.20	17.0	6.20	0.70	0.32	2.10	0.43	3.40	0.08	2.50	0.1	121.0
15-16	80.0	3.90	2.00	1.20	5.00	0.78	39.00	0.32	33.00	9.00	17.0	6.20	0.70	0.31	2.10	0.43	3.10	0.07	2.30	0.1	117.0
16-17	77.0	3.90	2.00	1.20	5.00	0.75	38.00	0.32	32.00	8.90	17.0	6.10	0.69	0.32	2.00	0.40	3.20	0.07	2.30	0.1	114.0
17-18	78.0	4.00	2.00	1.20	4.90	0.78	39.00	0.33	32.00	9.00	17.0	6.30	0.69	0.32	2.10	0.37	3.20	0.08	2.40	0.1	113.0
18-19	77.0	3.90	2.00	1.20	4.90	0.79	39.00	0.31	33.00	8.90	17.0	6.30	0.71	0.31	2.10	0.41	3.20	0.07	2.40	0.1	112.0
19-20	80.0	3.90	2.10	1.20	5.00	0.78	39.00	0.34	33.00	9.00	17.0	6.10	0.71	0.31	2.10	0.38	3.20	0.07	2.40	0.1	116.0
20-21	79.0	3.90	2.10	1.20	5.00	0.79	39.00	0.34	34.00	9.20	17.0	6.20	0.72	0.32	2.10	0.41	3.30	0.07	2.30	0.1	118.0
21-22	78.0	4.00	2.00	1.30	4.80	0.78	39.00	0.34	34.00	9.30	17.0	5.90	0.72	0.32	2.10	0.36	3.40	0.07	2.40	0.1	114.0
22-23	77.0	4.00	2.10	1.20	5.00	0.78	40.00	0.33	33.00	9.20	16.0	6.10	0.72	0.32	2.10	0.37	3.20	0.08	2.40	0.1	111.0
23-24	80.0	3.80	2.00	1.20	4.80	0.81	42.00	0.34	34.00	9.50	17.0	6.30	0.73	0.32	2.20	0.38	3.40	0.07	2.50	0.1	118.0
24-25	78.0	4.00	2.10	1.20	4.80	0.75	38.00	0.35	33.00	9.00	17.0	6.10	0.70	0.32	2.10	0.39	3.20	0.08	2.40	0.1	115.0
25-26	84.0	4.00	2.00	1.20	4.80	0.78	41.00	0.34	35.00	9.50	17.0	6.00	0.72	0.33	2.20	0.40	3.40	0.07	2.50	0.1	118.0
26-27	83.0	4.30	2.00	1.20	4.90	0.80	42.00	0.34	36.00	10.00	17.0	6.00	0.74	0.35	2.20	0.39	3.50	0.08	2.50	0.1	121.0
27-28	82.0	3.90	2.10	1.20	5.00	0.80	40.00	0.33	34.00	9.20	17.0	6.30	0.74	0.31	2.20	0.40	3.30	0.07	2.60	0.1	119.0
28-29	79.0	3.90	2.00	1.20	4.80	0.78	39.00	0.33	34.00	9.10	17.0	6.20	0.71	0.32	2.10	0.37	3.30	0.07	2.20	0.1	116.0
29-30	77.0	3.90	2.00	1.20	4.90	0.79	38.00	0.32	32.00	8.80	16.0	6.00	0.70	0.32	2.10	0.37	3.10	0.07	2.20	0.1	115.0
30-31	76.0	4.00	2.00	1.30	5.00	0.79	38.00	0.32	32.00	8.80	17.0	6.00	0.71	0.33	2.10	0.37	3.20	0.07	2.30	0.1	114.0
31-32	77.0	3.90	2.00	1.20	4.80	0.79	39.00	0.32	32.00	8.60	17.0	6.10	0.71	0.32	2.10	0.42	3.10	0.11	2.20	0.1	112.0

Table 13 continued

Depth cm	Ce ppm	Dy ppm	Er ppm	Eu ppm	Gd ppm	Ho ppm	La ppm	Lu ppm	Nd ppm	Pr ppm	Sc ppm	Sm ppm	Tb ppm	Tm ppm	Yb ppm	Bi ppm	Hf ppm	In ppm	Sn ppm	Te ppm	Zr ppm
32-33	81.0	4.00	2.10	1.30	4.80	0.80	40.00	0.33	34.00	9.00	17.0	6.30	0.73	0.34	2.20	0.38	3.30	0.07	2.40	0.1	120.0
33-34	81.0	4.00	2.10	1.20	4.80	0.80	40.00	0.35	34.00	9.50	17.0	6.00	0.71	0.33	2.10	0.35	3.30	0.08	2.30	0.1	119.0
34-35	77.0	4.00	2.10	1.20	4.80	0.77	38.00	0.34	32.00	9.30	17.0	6.00	0.69	0.32	2.00	0.35	3.20	0.08	2.30	0.1	115.0
35-36	78.0	4.00	2.10	1.20	4.90	0.79	39.00	0.33	34.00	9.20	17.0	6.00	0.73	0.33	2.20	0.38	3.40	0.07	2.40	0.1	117.0
36-37	77.0	4.00	2.10	1.20	4.90	0.75	41.00	0.33	34.00	9.60	17.0	6.10	0.72	0.32	2.10	0.36	3.30	0.07	3.00	0.1	116.0
37-38	77.0	3.90	2.10	1.20	4.80	0.77	41.00	0.33	33.00	9.30	16.0	6.20	0.72	0.32	2.10	0.37	3.30	0.08	2.40	0.1	113.0
38-39	76.0	3.90	2.00	1.20	4.90	0.78	38.00	0.33	32.00	9.00	17.0	6.20	0.72	0.32	2.10	0.39	3.20	0.07	2.30	0.1	117.0
39-40	78.0	4.00	2.00	1.20	4.80	0.77	38.00	0.34	32.00	8.90	17.0	6.20	0.71	0.34	2.20	0.40	3.20	0.07	2.30	0.1	117.0
40-41	80.0	4.20	2.00	1.30	4.70	0.77	41.00	0.34	36.00	9.70	17.0	6.00	0.72	0.35	2.20	0.38	3.50	0.08	2.50	0.1	120.0
41-42	79.0	4.00	2.00	1.20	4.90	0.78	40.00	0.32	34.00	9.10	17.0	6.10	0.74	0.32	2.10	0.39	3.30	0.07	2.30	0.1	115.0
42-43	79.0	4.00	2.00	1.20	4.90	0.79	39.00	0.33	34.00	9.10	17.0	6.20	0.72	0.32	2.10	0.40	3.30	0.07	2.20	0.1	117.0
43-44	78.0	4.00	2.00	1.30	5.10	0.78	40.00	0.32	33.00	9.10	17.0	6.10	0.71	0.32	2.10	0.38	3.20	0.07	2.30	0.1	115.0
44-45	80.0	4.00	2.00	1.20	5.10	0.78	40.00	0.33	33.00	9.10	17.0	6.20	0.70	0.32	2.10	0.39	3.20	0.07	2.20	0.1	118.0
45-46	78.0	4.00	2.00	1.20	4.80	0.79	39.00	0.32	33.00	8.90	17.0	6.20	0.71	0.32	2.10	0.35	3.20	0.07	2.20	0.1	112.0
46-47	78.0	3.90	2.00	1.20	4.90	0.76	39.00	0.31	32.00	8.80	17.0	6.10	0.68	0.31	2.00	0.35	3.10	0.07	2.20	0.1	111.0
47-48	79.0	3.90	2.00	1.20	4.90	0.79	39.00	0.34	33.00	9.00	16.0	6.10	0.71	0.32	2.10	0.38	3.20	0.07	2.20	0.1	117.0
48-49	79.0	3.80	2.10	1.20	4.90	0.75	39.00	0.34	34.00	9.30	17.0	6.00	0.70	0.31	2.00	0.39	3.20	0.07	2.30	0.1	116.0
49-50	78.0	4.00	2.10	1.20	4.90	0.81	39.00	0.33	34.00	9.20	17.0	6.00	0.74	0.32	2.10	0.38	3.40	0.07	2.30	0.1	114.0
50-51	78.0	4.00	2.10	1.20	5.00	0.80	41.00	0.33	34.00	9.50	16.0	6.10	0.75	0.33	2.20	0.37	3.40	0.07	2.30	0.1	113.0
51-52	82.0	4.00	2.00	1.20	5.00	0.79	42.00	0.34	35.00	9.60	16.0	6.30	0.74	0.33	2.20	0.37	3.30	0.08	2.40	0.1	117.0
52-53	81.0	4.10	2.10	1.30	5.00	0.80	40.00	0.35	34.00	9.60	17.0	6.20	0.73	0.34	2.20	0.39	3.30	0.07	2.40	0.1	118.0
53-54	83.0	4.10	2.00	1.20	4.90	0.81	40.00	0.34	36.00	9.40	16.0	6.20	0.75	0.34	2.20	0.41	3.20	0.07	4.90	0.1	119.0
54-55	81.0	4.20	2.10	1.20	4.90	0.80	41.00	0.34	35.00	9.60	17.0	6.10	0.72	0.34	2.20	0.39	3.50	0.08	2.50	0.1	118.0
55-56	81.0	4.00	2.10	1.20	5.00	0.81	40.00	0.33	34.00	8.90	16.0	6.30	0.76	0.31	2.20	0.40	3.20	0.07	2.30	0.1	118.0
56-57	79.0	3.80	2.00	1.20	4.80	0.76	39.00	0.32	34.00	9.20	17.0	6.00	0.69	0.31	2.10	0.42	3.20	0.07	2.20	0.1	116.0
57-58	80.0	4.00	2.00	1.30	5.00	0.80	40.00	0.33	34.00	9.40	17.0	6.20	0.72	0.33	2.10	0.38	3.30	0.07	2.20	0.1	119.0
58-59	77.0	4.00	2.10	1.20	5.00	0.78	38.00	0.34	32.00	8.80	16.0	6.10	0.69	0.34	2.10	0.37	3.30	0.07	2.20	0.1	117.0
59-60	77.0	4.00	2.00	1.20	4.90	0.78	39.00	0.32	32.00	8.90	17.0	6.10	0.70	0.32	2.20	0.34	3.30	0.07	2.20	0.1	150.0
60-61	77.0	4.10	2.00	1.30	5.00	0.82	40.00	0.32	33.00	9.00	17.0	6.40	0.72	0.33	2.10	0.37	3.30	0.07	2.30	0.1	114.0
61-62	81.0	3.90	2.00	1.20	4.80	0.75	39.00	0.34	34.00	9.30	17.0	6.00	0.69	0.32	2.00	0.35	3.20	0.08	2.20	0.1	118.0
62-63	78.0	4.10	2.10	1.20	5.00	0.80	39.00	0.35	34.00	9.20	17.0	6.10	0.73	0.33	2.20	0.38	3.40	0.07	2.50	0.1	118.0
63-64	80.0	4.20	2.20	1.30	5.10	0.83	40.00	0.34	35.00	9.30	17.0	6.20	0.77	0.34	2.20	0.40	3.50	0.07	2.40	0.1	117.0
64-65	76.0	4.10	2.10	1.20	4.90	0.79	41.00	0.33	33.00	9.50	17.0	6.10	0.73	0.33	2.20	0.37	3.40	0.08	2.40	0.1	113.0
65-66	80.0	3.90	2.10	1.20	5.10	0.80	41.00	0.33	33.00	9.40	16.0	6.40	0.72	0.32	2.10	0.36	3.20	0.07	2.40	0.1	116.0

Table 13 continued

Depth cm	Ce ppm	Dy ppm	Er ppm	Eu ppm	Gd ppm	Ho ppm	La ppm	Lu ppm	Nd ppm	Pr ppm	Sc ppm	Sm ppm	Tb ppm	Tm ppm	Yb ppm	Bi ppm	Hf ppm	In ppm	Sn ppm	Te ppm	Zr ppm
66-67	79.0	4.00	2.00	1.20	4.90	0.78	38.00	0.34	34.00	9.20	16.0	6.30	0.72	0.33	2.10	0.39	3.10	0.07	2.40	0.1	114.0
67-68	80.0	3.90	2.00	1.20	4.80	0.77	40.00	0.34	34.00	9.20	16.0	6.00	0.73	0.33	2.20	0.39	3.30	0.07	2.50	0.1	120.0
68-69	77.0	4.30	2.10	1.20	5.00	0.82	40.00	0.35	34.00	9.40	17.0	6.10	0.74	0.35	2.20	0.39	3.40	0.07	2.40	0.1	115.0
69-70	80.0	4.10	2.00	1.20	4.90	0.78	41.00	0.34	36.00	9.90	17.0	6.00	0.72	0.34	2.20	0.38	3.50	0.08	2.50	0.1	117.0
70-71	79.0	3.90	2.00	1.20	4.70	0.77	40.00	0.33	34.00	9.20	16.0	6.00	0.70	0.32	2.10	0.41	3.40	0.07	2.50	0.1	118.0
71-72	80.0	4.00	2.10	1.30	5.00	0.78	39.00	0.33	33.00	9.20	17.0	6.20	0.71	0.34	2.10	0.37	3.20	0.08	2.20	0.1	118.0
72-73	76.0	3.90	2.00	1.20	5.00	0.78	38.00	0.32	33.00	8.90	16.0	6.10	0.70	0.32	2.10	0.38	3.20	0.07	2.10	0.1	111.0
73-74	78.0	4.00	2.00	1.30	4.90	0.78	39.00	0.32	33.00	8.90	16.0	6.20	0.70	0.32	2.10	0.38	3.20	0.07	2.20	0.1	149.0
74-75	79.0	4.20	2.10	1.30	5.20	0.83	40.00	0.34	34.00	9.00	17.0	6.60	0.72	0.33	2.20	0.37	3.30	0.07	2.30	0.1	116.0
75-76	81.0	3.90	2.10	1.20	4.80	0.78	39.00	0.35	33.00	9.30	17.0	6.10	0.70	0.32	2.10	0.38	3.20	0.07	2.20	0.1	118.0
76-77	82.0	3.90	2.10	1.20	5.00	0.79	40.00	0.35	34.00	9.30	17.0	6.20	0.71	0.32	2.10	0.37	3.30	0.07	2.30	0.1	118.0
77-78	81.0	4.00	2.10	1.20	4.90	0.78	40.00	0.35	34.00	9.60	17.0	6.10	0.71	0.34	2.10	0.38	3.40	0.07	2.40	0.1	117.0
78-79	82.0	4.00	2.10	1.30	4.90	0.79	41.00	0.31	35.00	9.60	17.0	6.00	0.72	0.32	2.20	0.39	3.30	0.08	2.50	0.1	119.0
79-80	81.0	4.00	2.10	1.20	5.00	0.83	42.00	0.34	35.00	9.40	17.0	6.30	0.74	0.33	2.20	0.38	3.40	0.07	2.50	0.1	121.0
80-81	81.0	3.80	2.00	1.20	4.80	0.74	40.00	0.34	34.00	9.60	17.0	6.10	0.69	0.31	2.10	0.37	3.10	0.07	2.40	0.1	117.0
81-82	82.0	4.10	2.10	1.20	4.90	0.79	40.00	0.35	35.00	9.40	17.0	6.20	0.74	0.34	2.20	0.40	3.30	0.08	2.50	0.1	118.0
82-83	81.0	4.30	2.10	1.20	4.80	0.78	41.00	0.36	36.00	9.80	17.0	6.20	0.73	0.35	2.10	0.38	3.40	0.08	2.50	0.1	119.0
83-84	84.0	4.10	2.10	1.20	4.90	0.82	42.00	0.34	36.00	9.70	17.0	6.20	0.74	0.35	2.20	0.39	3.50	0.07	2.60	0.1	117.0
84-85	83.0	4.00	2.10	1.20	5.10	0.81	40.00	0.34	34.00	9.00	17.0	6.20	0.72	0.32	2.20	0.39	3.30	0.07	2.30	0.1	121.0
85-86	82.0	4.00	2.00	1.20	4.90	0.80	41.00	0.33	35.00	9.40	17.0	6.10	0.72	0.33	2.10	0.42	3.30	0.08	2.30	0.1	118.0
86-87	81.0	4.10	2.10	1.30	5.30	0.83	40.00	0.34	34.00	9.30	17.0	6.40	0.73	0.33	2.20	0.41	3.40	0.07	2.30	0.1	122.0
87-88	79.0	4.00	2.00	1.20	5.00	0.79	39.00	0.32	33.00	9.00	17.0	6.00	0.69	0.33	2.10	0.39	3.20	0.07	2.40	0.1	114.0
88-89	80.0	4.00	2.00	1.20	5.00	0.78	40.00	0.32	32.00	9.20	17.0	6.20	0.69	0.32	2.10	0.37	3.20	0.07	2.20	0.1	113.0
89-90	78.0	4.00	2.00	1.20	5.00	0.77	39.00	0.32	32.00	8.70	17.0	6.30	0.70	0.31	2.10	0.48	3.20	0.17	2.20	0.1	111.0
90-91	79.0	4.10	2.20	1.20	4.90	0.80	40.00	0.34	34.00	9.20	17.0	6.00	0.73	0.34	2.20	0.36	3.40	0.07	2.30	0.1	119.0
91-92	79.0	3.80	2.10	1.20	4.70	0.76	38.00	0.32	33.00	9.20	17.0	6.10	0.69	0.30	2.00	0.37	3.20	0.07	2.30	0.1	115.0
92-93	77.0	4.00	2.10	1.20	4.70	0.77	39.00	0.34	33.00	9.10	17.0	5.80	0.68	0.33	2.10	0.37	3.40	0.08	2.40	0.1	114.0
93-94	78.0	4.00	2.10	1.20	4.80	0.78	40.00	0.33	34.00	9.20	17.0	5.90	0.73	0.33	2.20	0.39	3.40	0.07	2.30	0.1	116.0
94-95	77.0	3.90	2.00	1.20	4.80	0.78	41.00	0.33	34.00	9.50	17.0	6.00	0.72	0.32	2.10	0.34	3.30	0.08	2.50	0.1	114.0
95-96	78.0	3.90	2.00	1.20	4.70	0.76	39.00	0.33	34.00	9.40	17.0	5.90	0.68	0.33	2.00	0.37	3.20	0.07	2.40	0.1	113.0
96-97	80.0	4.00	2.00	1.20	4.80	0.81	40.00	0.34	35.00	9.40	17.0	6.20	0.73	0.33	2.20	0.40	3.30	0.07	2.60	0.1	117.0
97-98	80.0	4.30	2.00	1.30	4.90	0.81	43.00	0.36	36.00	10.00	17.0	6.10	0.73	0.35	2.20	0.39	3.50	0.08	2.60	0.1	122.0
98-99	82.0	4.20	2.10	1.20	4.80	0.78	41.00	0.35	35.00	9.60	17.0	6.10	0.71	0.34	2.20	0.38	3.40	0.08	2.40	0.1	116.0
99-100	82.0	3.80	2.00	1.20	4.90	0.75	40.00	0.32	34.00	9.20	17.0	6.00	0.71	0.29	2.10	0.36	3.10	0.08	2.20	0.1	117.0

Table 13 continued

Depth cm	Ce ppm	Dy ppm	Er ppm	Eu ppm	Gd ppm	Ho ppm	La ppm	Lu ppm	Nd ppm	Pr ppm	Sc ppm	Sm ppm	Tb ppm	Tm ppm	Yb ppm	Bi ppm	Hf ppm	In ppm	Sn ppm	Te ppm	Zr ppm
100-101	79.0	3.90	2.00	1.20	4.80	0.77	39.00	0.33	34.00	9.20	17.0	6.00	0.68	0.31	2.10	0.36	3.20	0.07	2.20	0.1	114.0
101-102	80.0	3.80	2.00	1.20	4.90	0.76	39.00	0.32	34.00	9.20	17.0	6.20	0.68	0.31	2.00	0.35	3.10	0.07	2.20	0.1	116.0
102-103	77.0	4.00	2.00	1.20	5.00	0.78	38.00	0.33	33.00	9.00	16.0	6.10	0.71	0.33	2.10	0.40	3.20	0.07	2.20	0.1	114.0
103-104	76.0	4.10	2.00	1.20	5.00	0.79	38.00	0.32	32.00	8.80	17.0	6.20	0.71	0.33	2.20	0.38	3.20	0.07	2.20	0.1	110.0
104-105	77.0	4.00	2.00	1.20	4.90	0.80	54.00	0.32	33.00	8.70	17.0	6.20	0.72	0.32	2.20	0.35	3.20	0.07	2.20	0.1	117.0
105-106	81.0	4.00	2.10	1.20	5.00	0.79	40.00	0.35	34.00	9.30	17.0	6.20	0.72	0.33	2.10	0.37	3.40	0.07	2.30	0.1	119.0
106-107	79.0	3.90	2.10	1.20	4.70	0.77	39.00	0.33	34.00	8.90	17.0	6.00	0.71	0.32	2.10	0.38	3.20	0.07	2.30	0.1	115.0
107-108	79.0	3.90	2.10	1.20	4.90	0.79	39.00	0.34	34.00	9.30	17.0	6.10	0.72	0.32	2.10	0.41	3.40	0.07	2.40	0.1	154.0
108-109	77.0	4.10	2.10	1.30	4.80	0.77	39.00	0.34	34.00	9.30	17.0	6.00	0.73	0.33	2.10	0.36	3.50	0.07	2.40	0.1	117.0
109-110	79.0	4.00	2.00	1.20	4.90	0.79	41.00	0.33	34.00	9.60	17.0	6.10	0.73	0.33	2.10	0.37	3.30	0.07	2.60	0.1	116.0
110-111	79.0	4.00	2.10	1.20	4.90	0.78	39.00	0.34	34.00	9.30	17.0	6.30	0.71	0.33	2.20	0.39	3.20	0.07	2.40	0.1	114.0
111-112	81.0	4.00	2.10	1.20	4.90	0.77	39.00	0.35	34.00	9.40	17.0	6.00	0.70	0.32	2.20	0.38	3.20	0.07	2.40	0.1	117.0
112-113	77.0	4.00	2.00	1.20	4.90	0.77	39.00	0.33	34.00	9.40	17.0	6.00	0.71	0.33	2.10	0.41	3.40	0.07	2.50	0.1	118.0
113-114	82.0	3.90	2.00	1.20	4.80	0.76	40.00	0.33	34.00	9.50	17.0	5.90	0.70	0.33	2.00	0.36	3.30	0.08	2.40	0.1	116.0
114-115	78.0	3.80	2.00	1.20	4.80	0.76	38.00	0.32	33.00	8.90	17.0	6.00	0.71	0.31	2.00	0.36	3.20	0.08	2.30	0.1	118.0
115-116	77.0	3.90	2.00	1.20	4.80	0.78	39.00	0.33	33.00	9.10	17.0	6.00	0.69	0.32	2.10	0.41	3.30	0.07	2.20	0.1	114.0
116-117	77.0	4.00	2.00	1.20	4.90	0.78	39.00	0.32	33.00	8.90	17.0	6.20	0.71	0.32	2.10	0.36	3.20	0.07	2.30	0.1	115.0
117-118	75.0	3.80	2.00	1.20	4.90	0.77	38.00	0.31	32.00	8.80	17.0	6.00	0.67	0.32	2.00	0.37	3.20	0.08	2.20	0.1	115.0
118-119	74.0	3.80	1.90	1.20	4.80	0.74	37.00	0.31	31.00	8.70	16.0	5.90	0.66	0.30	2.00	0.36	3.10	0.07	2.30	0.1	111.0
119-120	75.0	3.80	2.00	1.20	4.80	0.77	38.00	0.32	31.00	8.50	17.0	6.10	0.68	0.32	2.10	0.36	3.10	0.07	2.30	0.1	110.0
120-121	79.0	4.10	2.10	1.20	4.90	0.80	40.00	0.34	34.00	9.40	17.0	6.20	0.73	0.34	2.10	0.37	3.40	0.07	2.40	0.1	120.0
121-122	78.0	4.00	2.10	1.20	4.90	0.81	39.00	0.34	34.00	9.20	17.0	6.20	0.72	0.32	2.10	0.37	3.30	0.07	2.40	0.1	118.0
122-123	78.0	3.90	2.10	1.20	4.80	0.76	38.00	0.34	32.00	9.10	17.0	6.00	0.70	0.31	2.10	0.36	3.30	0.07	2.30	0.1	115.0
123-124	78.0	3.90	2.10	1.20	4.80	0.76	38.00	0.31	33.00	8.90	17.0	5.90	0.72	0.31	2.10	0.36	3.30	0.07	2.20	0.1	115.0
124-125	77.0	3.90	2.00	1.20	4.90	0.76	39.00	0.33	32.00	9.20	17.0	6.10	0.72	0.32	2.10	0.36	3.20	0.08	2.40	0.1	113.0
125-126	79.0	3.90	2.00	1.20	4.90	0.80	41.00	0.34	33.00	9.20	17.0	6.20	0.72	0.33	2.20	0.37	3.40	0.07	2.40	0.1	115.0
126-127	83.0	4.20	2.10	1.20	4.90	0.79	41.00	0.34	36.00	9.90	17.0	6.20	0.73	0.33	2.20	0.41	3.40	0.08	2.50	0.1	122.0
127-128	85.0	4.10	2.10	1.30	4.90	0.76	41.00	0.35	35.00	10.00	17.0	6.10	0.72	0.33	2.10	0.39	3.40	0.08	2.40	0.1	119.0
128-129	84.0	4.20	2.10	1.30	4.90	0.80	42.00	0.35	36.00	9.70	17.0	6.10	0.76	0.35	2.20	0.37	3.50	0.08	2.50	0.1	120.0
129-130	82.0	4.00	2.10	1.20	4.90	0.77	40.00	0.33	33.00	9.20	17.0	6.10	0.72	0.32	2.10	0.36	3.20	0.07	2.20	0.1	122.0
130-131	81.0	3.90	2.00	1.20	4.90	0.80	41.00	0.33	35.00	9.20	17.0	6.10	0.71	0.32	2.20	0.41	3.40	0.07	2.30	0.1	119.0
131-132	83.0	4.10	2.00	1.30	5.10	0.80	40.00	0.34	34.00	9.40	17.0	6.50	0.72	0.32	2.10	0.37	3.30	0.08	2.30	0.1	121.0
132-133	76.0	3.90	2.00	1.20	5.10	0.79	38.00	0.33	33.00	8.80	17.0	6.20	0.71	0.32	2.10	0.37	3.20	0.07	2.30	0.1	115.0
133-134	74.0	3.90	2.00	1.20	5.10	0.77	37.00	0.33	30.00	8.70	17.0	6.00	0.68	0.32	2.10	0.38	3.30	0.07	2.10	0.1	112.0

Table 13 continued

Depth cm	Ce ppm	Dy ppm	Er ppm	Eu ppm	Gd ppm	Ho ppm	La ppm	Lu ppm	Nd ppm	Pr ppm	Sc ppm	Sm ppm	Tb ppm	Tm ppm	Yb ppm	Bi ppm	Hf ppm	In ppm	Sn ppm	Te ppm	Zr ppm
134-135	76.0	3.90	2.00	1.20	4.70	0.77	39.00	0.31	32.00	8.80	17.0	6.00	0.68	0.31	2.10	0.33	3.10	0.07	2.20	0.1	111.0
135-136	78.0	3.80	1.90	1.20	4.80	0.77	40.00	0.31	33.00	9.00	17.0	6.20	0.69	0.31	2.10	0.33	3.10	0.07	2.30	0.1	115.0
136-137	79.0	4.00	2.10	1.20	5.10	0.80	39.00	0.34	33.00	9.20	17.0	6.10	0.71	0.32	2.10	0.38	3.20	0.07	2.30	0.1	115.0
137-138	77.0	4.00	2.10	1.20	4.90	0.77	39.00	0.34	32.00	9.20	17.0	6.10	0.71	0.31	2.10	0.35	3.30	0.07	2.30	0.1	115.0
138-139	79.0	4.00	2.10	1.20	4.90	0.77	39.00	0.33	33.00	9.10	17.0	6.00	0.72	0.32	2.10	0.36	3.40	0.07	2.50	0.1	114.0
139-140	77.0	4.00	2.00	1.20	4.80	0.76	40.00	0.32	34.00	9.30	17.0	6.10	0.72	0.32	2.10	0.35	3.30	0.07	2.50	0.1	113.0
140-141	79.0	3.80	2.00	1.20	4.70	0.77	41.00	0.33	33.00	9.30	17.0	6.10	0.72	0.32	2.10	0.36	3.30	0.07	2.50	0.1	115.0
141-142	78.0	3.90	2.00	1.20	4.80	0.75	38.00	0.34	34.00	9.20	17.0	6.10	0.71	0.32	2.10	0.37	3.20	0.08	2.50	0.1	115.0
142-143	74.0	4.00	2.00	1.20	4.70	0.78	39.00	0.33	34.00	9.20	16.0	5.80	0.71	0.33	2.10	0.37	3.30	0.07	2.40	0.1	112.0
143-144	82.0	3.90	2.00	1.20	4.70	0.75	40.00	0.33	35.00	9.70	17.0	5.80	0.68	0.33	2.00	0.35	3.30	0.07	2.50	0.1	117.0
144-145	82.0	3.90	2.10	1.20	5.00	0.77	40.00	0.33	34.00	9.30	17.0	6.10	0.71	0.30	2.10	0.37	3.20	0.07	2.30	0.1	120.0
STANDARDS																					
8010	45.0	2.60	1.30	0.97	3.20	0.51	23.00	0.21	22.00	5.70	10.0	4.00	0.48	0.21	1.40	0.10	3.80	0.02	0.76	-0.1	
8010	46.0	2.50	1.30	0.99	3.30	0.49	23.00	0.21	21.00	5.80	9.5	4.00	0.46	0.20	1.30	-0.05	3.70	0.02	0.73	-0.1	
8010	47.0	2.60	1.40	1.00	3.40	0.52	23.00	0.21	22.00	5.60	9.2	4.20	0.49	0.20	1.40	0.05	3.60	0.02	0.71	-0.1	
8010	45.0	2.70	1.30	0.99	3.30	0.50	24.00	0.21	22.00	5.70	10.0	4.20	0.47	0.21	1.40	0.05	3.40	0.02	0.73	-0.1	
8010	47.0	2.60	1.30	0.98	3.30	0.51	23.00	0.21	21.00	5.60	9.5	4.30	0.48	0.21	1.30	-0.05	3.50	0.02	0.71	-0.1	
STSD-1	50.0	5.20	3.00	1.50	6.20	1.10	26.00	0.49	32.00	7.70	13.0	6.40	0.91	0.45	3.10	0.43	2.20	0.07	2.40	0.1	85.0
DUPLICATES																					
70-71 cm	77.0	3.80	2.00	1.20	4.90	0.77	38.00	0.32	33.00	8.80	17.0	6.00	0.69	0.32	2.10	0.39	3.10	0.07	2.20	0.1	112.0
44-45 cm	78.0	4.00	2.00	1.20	5.00	0.77	39.00	0.32	33.00	9.10	17.0	6.10	0.69	0.33	2.00	0.38	3.20	0.08	2.20	0.1	113.0
89-90 cm	78.0	3.90	2.00	1.20	5.00	0.80	40.00	0.31	33.00	8.90	17.0	6.30	0.71	0.31	2.10	0.35	3.20	0.07	2.20	0.1	115.0
5-6 cm	78.0	3.90	2.10	1.20	4.90	0.78	39.00	0.34	33.00	9.10	17.0	6.10	0.71	0.31	2.10	0.42	3.20	0.08	2.70	0.1	115.0
35-36 cm	77.0	4.20	2.10	1.20	5.00	0.81	39.00	0.33	33.00	9.20	17.0	6.10	0.75	0.33	2.20	0.38	3.50	0.07	2.40	0.1	113.0
94-95cm	77.0	3.90	2.00	1.20	4.90	0.78	41.00	0.33	34.00	9.40	17.0	6.10	0.72	0.31	2.10	0.36	3.30	0.07	2.40	0.1	114.0
10-11 cm	76.0	3.90	2.00	1.20	4.90	0.78	40.00	0.34	34.00	9.20	16.0	6.10	0.73	0.32	2.20	0.46	3.30	0.08	2.70	0.1	117.0
40-41 cm	80.0	4.10	2.10	1.20	4.80	0.75	40.00	0.35	35.00	9.70	17.0	6.00	0.70	0.33	2.10	0.38	3.40	0.08	2.40	0.1	120.0

Table 14. Corrected elemental analysis results for Lake Winnipeg 99-900 core 4

Depth	As	Hg	Al	Sb	Ba	Be	Bi	Cd	Ca	Ce	Cs	Cr	Co	Cu	Ga	Ge	Fe	La	Pb	Li	Mg	Mn
cm	ppm	ppb	%	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	%	ppm
0-1	5	90	8.42	1.4	476	2.05	0.48	0.60	1.17	75.3	7.61	103	16.1	32	23.7	1.6	4.09	41.5	28.5	60.8	1.46	1005
1-2	5	90	8.37	0.6	510	2.09	0.45	0.54	1.15	73.5	7.43	108	15.9	31	22.7	1.6	4.03	40.5	26.5	56.5	1.47	935
2-3	6	100	8.40	0.6	510	1.99	0.46	0.56	1.16	77.1	7.95	102	17.3	29	24.5	1.7	4.05	42.5	27.0	61.8	1.47	1060
3-4	5	90	8.45	0.5	520	2.28	0.43	0.52	1.18	71.4	7.27	104	16.9	29	23.5	1.7	4.12	39.0	25.5	58.9	1.50	1120
4-5	6	90	8.88	0.4	500	2.12	0.39	0.52	1.18	72.8	7.09	110	16.7	31	23.2	1.7	4.26	37.5	25.0	57.4	1.54	1220
5-6	5	90	8.53	0.5	500	2.47	0.46	0.54	1.22	75.1	7.51	107	17.3	30	24.6	1.8	4.15	40.5	27.5	61.0	1.51	1255
6-7	2	100	8.56	0.5	520	2.06	0.43	0.56	1.20	75.8	7.13	105	16.7	31	23.3	1.8	4.07	40.0	26.5	59.9	1.51	1200
7-8	1	90	8.41	0.5	500	2.25	0.46	0.50	1.17	79.4	7.60	105	16.7	33	23.6	1.8	3.97	42.0	28.5	59.4	1.47	1165
8-9	8	90	8.55	0.8	500	1.79	0.45	0.50	1.18	73.4	7.26	101	15.1	29	23.8	1.6	4.11	38.5	26.0	57.2	1.50	1215
9-10	6	110	7.89	0.8	480	2.04	0.43	0.52	1.09	77.2	7.68	98	16.1	30	24.8	1.8	3.79	41.0	26.5	60.2	1.38	1105
10-11	3	40	8.34	0.8	510	1.98	0.45	0.52	1.19	77.0	7.55	103	16.1	31	24.1	1.7	4.04	40.5	28.0	60.8	1.45	1110
11-12	1	90	8.52	0.8	500	1.77	0.44	0.48	1.16	76.2	7.42	104	15.7	31	23.9	1.6	4.07	39.5	26.5	60.4	1.48	1115
12-13	2	100	8.36	1.2	510	2.22	0.50	0.56	1.16	72.9	7.46	102	17.2	33	23.1	1.7	3.98	40.5	27.5	56.8	1.44	1075
13-14	0.5	100	8.41	1.2	510	1.81	0.44	0.58	1.11	73.6	7.36	101	17.8	31	23.1	1.7	3.97	40.0	28.0	58.4	1.41	1085
14-15	0.5	100	8.49	1.0	520	1.95	0.47	0.58	1.09	75.0	7.36	101	17.4	31	22.9	1.7	4.20	41.0	29.0	58.8	1.44	1120
15-16	5	100	8.67	1.1	530	1.89	0.50	0.60	1.11	78.0	7.61	102	17.8	31	23.8	1.7	4.14	42.5	28.0	62.0	1.44	1075
16-17	5	80	8.52	1.3	536	1.85	0.49	0.60	1.05	76.6	7.67	100	17.1	30	23.4	1.6	4.16	42.5	25.5	60.3	1.43	1130
17-18	4	80	8.70	0.5	540	1.94	0.45	0.58	1.04	73.4	7.33	108	18.1	31	23.3	1.7	4.28	40.0	24.0	58.8	1.45	1125
18-19	4	60	7.97	0.5	470	1.99	0.44	0.52	0.99	72.1	7.40	96	17.1	28	23.4	1.7	3.94	39.5	23.0	60.9	1.33	1005
19-20	4	60	8.24	0.4	510	2.08	0.43	0.48	0.99	74.2	7.57	97	17.9	27	23.6	1.7	4.10	40.0	23.0	60.8	1.38	1075
20-21	4	60	8.65	0.4	540	2.37	0.42	0.50	1.02	74.7	7.54	105	18.1	29	24.6	1.7	4.31	41.0	21.5	60.9	1.43	1155
21-22	3	50	8.51	0.4	520	2.17	0.40	0.46	1.02	74.4	7.31	108	17.3	28	23.0	1.7	4.12	40.0	21.0	57.2	1.42	1115
22-23	1	60	8.33	0.4	520	2.36	0.42	0.46	1.01	77.1	7.33	104	16.5	28	23.5	1.7	3.89	41.5	21.0	58.1	1.38	1135
23-24	0.5	60	8.83	0.4	530	2.05	0.47	0.50	1.02	80.9	7.60	112	17.3	30	24.3	1.8	4.10	43.0	22.0	59.9	1.44	1175
24-25	6	40	8.32	0.7	530	1.84	0.42	0.46	0.99	75.9	7.37	100	16.7	28	23.4	1.7	4.09	39.5	21.0	59.0	1.36	1135
25-26	5	50	8.61	0.7	530	2.59	0.41	0.48	1.03	75.6	7.59	100	17.1	31	23.8	1.8	4.11	39.5	20.0	61.0	1.43	1165
26-27	2	100	8.62	0.7	530	1.98	0.40	0.40	1.07	75.5	7.61	101	16.7	27	24.2	1.7	4.12	39.5	19.5	60.8	1.45	1195
27-28	0.5	40	8.53	0.6	540	2.02	0.39	0.40	1.05	75.5	7.37	97	17.1	26	24.7	1.7	4.09	39.0	19.0	61.6	1.42	1160
28-29	0.5	40	8.37	0.8	520	1.97	0.41	0.40	1.05	70.2	7.31	97	17.6	26	22.8	1.7	4.02	39.0	19.5	56.8	1.42	1150
29-30	0.5	40	8.35	0.9	520	2.16	0.48	0.44	1.12	74.5	7.56	97	18.6	28	23.4	1.7	3.99	41.0	20.5	59.4	1.43	1140
30-31	0.5	50	8.44	0.8	530	2.15	0.41	0.46	1.14	71.3	7.36	98	17.6	27	22.4	1.6	4.12	39.0	20.5	58.2	1.48	1160
31-32	4	50	8.72	0.8	560	1.94	0.41	0.42	1.13	73.6	7.31	100	16.6	26	22.9	1.7	4.15	40.0	19.5	58.2	1.50	1230

Table 14 continued

Depth cm	As ppm	Hg ppb	Al %	Sb ppm	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ca %	Ce ppm	Cs ppm	Cr ppm	Co ppm	Cu ppm	Ga ppm	Ge ppm	Fe %	La ppm	Pb ppm	Li ppm	Mg %	Mn ppm
32-33	2	40	8.77	1.8	596	2.15	0.42	0.50	1.15	76.6	7.52	99	16.5	26	23.6	1.6	4.22	42.0	20.0	60.0	1.52	1250
33-34	2	40	8.65	0.4	550	1.95	0.39	0.46	1.14	74.4	7.44	101	16.7	26	23.1	1.7	4.03	41.5	19.0	58.3	1.49	1210
34-35	2	40	7.98	0.4	510	2.14	0.42	0.48	1.07	73.5	7.16	96	16.7	26	23.1	1.7	3.89	39.0	20.0	56.4	1.38	1175
35-36	3	40	8.50	0.3	530	2.13	0.41	0.50	1.10	74.1	7.33	99	16.5	27	23.1	1.7	4.02	40.5	19.5	58.1	1.45	1200
36-37	5	50	8.67	0.3	530	1.87	0.39	0.48	1.14	76.2	7.44	102	18.1	26	23.9	1.8	4.03	41.0	19.0	58.4	1.48	1165
37-38	6	40	8.19	0.3	490	2.22	0.39	0.48	1.07	74.1	7.46	99	17.9	25	23.9	1.9	3.88	40.0	19.0	61.9	1.40	1165
38-39	0.5	40	8.58	0.4	550	2.16	0.39	0.48	1.13	76.3	7.48	108	17.1	27	23.5	1.8	3.97	41.0	19.5	59.6	1.46	1200
39-40	0.5	40	6.97	0.3	440	2.65	0.39	0.48	0.97	73.2	7.15	85	16.1	21	22.4	1.7	3.26	38.5	19.5	56.7	1.22	1030
40-41	4	50	8.59	0.7	520	2.05	0.37	0.46	1.18	71.8	7.07	100	14.9	26	22.2	1.6	4.02	37.5	19.0	57.4	1.50	1275
41-42	4	50	8.37	0.6	520	1.89	0.38	0.46	1.18	71.0	7.09	99	14.5	27	22.2	1.6	3.84	37.5	19.5	57.2	1.49	1270
42-43	2	40	8.20	0.7	510	2.13	0.39	0.48	1.21	74.7	7.41	102	15.3	28	23.5	1.7	3.89	39.0	19.0	60.0	1.47	1215
43-44	0.5	40	8.22	0.7	490	1.87	0.40	0.50	1.17	75.1	7.28	95	15.1	25	23.3	1.7	3.88	39.0	19.0	58.0	1.45	1270
44-45	0.5	40	8.50	1.6	530	2.02	0.41	0.54	1.18	73.7	7.66	101	17.6	25	23.6	1.8	3.98	40.5	20.0	58.6	1.48	1255
45-46	0.5	40	8.29	0.9	510	2.41	0.43	0.54	1.16	73.3	7.61	98	17.4	27	23.5	1.7	3.99	40.5	21.0	60.0	1.47	1250
46-47	0.5	40	8.39	0.9	510	2.20	0.45	0.52	1.21	73.7	7.51	104	18.8	26	22.9	1.7	4.07	40.0	21.0	59.2	1.51	1210
47-48	6	40	8.02	1.0	490	1.90	0.40	0.50	1.15	70.7	7.26	111	17.6	24	22.2	1.7	3.86	38.0	18.5	56.4	1.42	1180
48-49	3	50	8.25	3.0	546	1.80	0.41	0.50	1.22	73.2	7.57	94	15.5	26	22.7	1.6	3.99	40.5	30.0	59.7	1.47	1280
49-50	3	50	8.32	0.4	530	1.80	0.42	0.50	1.12	75.3	7.69	95	18.1	26	23.0	1.7	4.08	41.0	20.0	59.4	1.45	1220
50-51	3	40	8.24	0.4	530	1.94	0.41	0.46	1.09	72.3	7.41	99	17.7	28	23.3	1.7	4.08	39.0	19.5	57.7	1.44	1215
51-52	3	40	7.91	0.8	500	2.23	0.39	0.46	1.03	72.4	7.48	93	16.7	26	23.9	1.8	3.83	38.5	19.5	60.8	1.35	1230
52-53	4	40	7.90	0.3	490	2.07	0.39	0.48	1.07	73.2	7.40	95	16.7	27	23.8	1.7	3.87	39.5	19.5	60.3	1.36	1200
53-54	4	40	8.72	0.3	520	2.02	0.41	0.42	1.07	73.6	7.62	102	16.1	28	23.5	1.8	4.23	39.5	19.5	61.2	1.48	1330
54-55	1	30	8.24	0.6	490	2.31	0.41	0.48	1.02	77.2	7.84	102	18.9	28	24.6	1.8	3.77	41.5	20.0	64.5	1.38	1150
55-56	0.5	40	8.79	0.4	540	2.25	0.43	0.52	1.05	79.2	8.00	102	19.5	29	24.6	1.8	4.20	42.0	21.0	61.4	1.47	1285
56-57	5	50	8.35	0.6	540	1.85	0.38	0.42	0.99	74.6	7.52	107	16.3	29	22.5	1.7	3.91	39.0	19.0	59.6	1.40	1255
57-58	4	40	8.48	0.7	520	2.04	0.40	0.42	0.98	76.5	7.74	103	16.5	26	24.2	1.7	4.02	40.0	19.5	61.4	1.38	1360
58-59	0.5	50	8.57	0.6	540	2.28	0.39	0.38	0.98	74.1	7.31	104	16.1	27	23.1	1.6	4.09	38.5	18.5	58.8	1.42	1400
59-60	3	40	8.86	0.7	530	2.27	0.38	0.38	1.02	76.3	7.63	103	16.1	27	24.5	1.7	4.26	39.5	18.5	62.2	1.47	1585
60-61	3	30	8.47	1.0	530	1.97	0.41	0.40	0.96	70.2	7.51	97	17.6	26	23.0	1.8	4.05	39.5	19.5	59.6	1.37	1465
61-62	0.5	30	8.71	0.8	560	1.86	0.39	0.40	0.99	72.8	7.56	102	16.8	29	22.9	1.7	4.24	40.0	19.5	60.2	1.43	1365
62-63	0.5	40	8.57	0.8	520	2.10	0.39	0.42	1.02	70.3	7.66	100	16.8	27	22.9	1.7	4.15	38.5	19.5	59.8	1.44	1245
63-64	0.5	40	8.31	1.8	530	1.90	0.46	0.40	1.00	68.0	7.36	97	17.8	26	22.6	1.7	4.03	37.0	18.0	56.6	1.39	1255

Table 14 continued

Depth cm	As ppm	Hg ppb	Al %	Sb ppm	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ca %	Ce ppm	Cs ppm	Cr ppm	Co ppm	Cu ppm	Ga ppm	Ge ppm	Fe %	La ppm	Pb ppm	Li ppm	Mg %	Mn ppm
64-65	2	40	8.71	4.0	566	2.20	0.40	0.46	1.00	72.7	7.88	97	16.3	27	23.1	1.7	4.21	40.5	20.5	61.0	1.44	1320
65-66	3	30	8.55	0.5	520	1.80	0.40	0.48	1.00	73.7	7.84	101	16.3	26	23.0	1.7	4.12	40.5	20.0	60.7	1.42	1280
66-67	3	30	8.19	0.4	480	2.44	0.38	0.40	0.98	70.0	7.51	104	14.9	27	23.2	1.7	3.92	38.5	18.5	59.2	1.36	1230
67-68	3	40	8.43	0.4	510	2.08	0.38	0.42	0.98	72.1	7.58	97	15.1	26	24.1	1.8	4.17	38.5	18.5	59.5	1.38	1300
68-69	4	40	8.37	0.3	530	2.13	0.39	0.42	0.98	72.1	7.40	98	16.3	26	23.6	1.8	4.05	38.5	19.0	61.0	1.38	1245
69-70	3	40	8.36	0.3	520	2.07	0.39	0.44	0.99	72.6	7.42	103	18.5	27	23.9	1.8	4.11	38.5	20.0	59.5	1.39	1290
70-71	0.5	30	8.54	0.3	520	1.76	0.39	0.44	1.01	74.9	7.44	99	20.5	26	23.4	1.7	4.10	40.5	20.0	59.4	1.40	1255
71-72	0.5	40	8.19	0.3	520	2.20	0.39	0.44	1.00	74.2	7.16	98	17.1	27	22.9	1.7	3.78	40.0	18.5	54.5	1.35	1220
72-73	4	40	8.31	0.6	530	1.85	0.39	0.44	1.06	72.4	7.18	102	14.3	29	22.1	1.6	3.76	38.0	19.0	57.0	1.42	1225
73-74	5	40	8.71	0.7	580	1.84	0.41	0.48	1.07	78.3	7.70	102	15.5	26	24.3	1.7	4.18	41.0	19.5	60.6	1.44	1325
74-75	4	60	8.45	0.7	550	1.88	0.38	0.40	1.08	75.2	7.47	100	15.5	26	23.4	1.7	3.91	39.5	19.0	61.0	1.43	1300
75-76	2	40	8.56	0.7	560	2.08	0.39	0.46	1.14	76.0	7.38	97	16.3	28	23.6	1.8	4.09	39.0	19.5	60.8	1.49	1225
76-77	0.5	40	8.22	1.2	520	2.32	0.41	0.54	1.14	72.7	7.46	94	18.2	26	23.5	1.8	3.91	40.0	20.5	58.4	1.43	1305
77-78	0.5	50	8.19	0.8	510	1.96	0.40	0.48	1.13	73.8	7.21	96	17.4	28	22.6	1.7	3.98	40.5	20.0	55.4	1.43	1275
78-79	0.5	50	8.38	0.9	540	2.25	0.43	0.56	1.17	78.6	7.81	99	19.2	28	23.9	1.7	4.11	42.0	22.0	59.4	1.46	1280
79-80	0.5	40	8.11	0.8	520	2.55	0.42	0.52	1.13	73.7	7.16	95	19.0	31	23.0	1.7	4.02	39.5	20.0	58.8	1.42	1260
80-81	3	40	8.32	2.8	546	2.00	0.44	0.48	1.13	74.5	7.43	94	16.3	27	22.0	1.6	4.09	40.5	21.0	57.9	1.45	1305
81-82	3	50	8.26	0.5	510	2.20	0.42	0.52	1.08	77.2	7.40	96	18.7	28	22.2	1.6	3.99	41.0	21.0	57.8	1.41	1270
82-83	3	40	8.39	0.3	550	2.34	0.40	0.52	1.11	72.9	7.12	96	17.7	28	22.5	1.7	4.16	39.5	20.0	56.5	1.45	1355
83-84	3	40	8.16	0.4	520	1.88	0.40	0.50	1.10	74.2	7:29	95	17.7	27	23.1	1.7	4.01	40.0	20.0	57.0	1.43	1280
84-85	5	40	7.83	0.5	510	2.58	0.40	0.56	1.11	76.4	7.15	95	17.3	27	23.3	1.7	3.82	40.0	20.5	57.9	1.39	1300
85-86	4	40	8.01	0.3	530	2.27	0.39	0.56	1.09	75.5	7.22	97	18.7	28	24.1	1.8	3.91	40.5	20.0	58.6	1.41	1230
86-87	1	30	8.03	0.3	520	2.16	0.39	0.46	1.02	72.9	7.04	95	17.5	26	23.1	1.7	3.91	37.5	18.5	58.3	1.38	1255
87-88	1	40	8.46	0.3	560	2.10	0.41	0.50	1.05	78.8	7.36	102	18.5	28	23.6	1.8	3.97	41.5	19.5	58.6	1.42	1310
88-89	6	50	8.28	0.7	510	2.00	0.40	0.52	1.05	76.5	7.38	101	16.1	28	22.6	1.7	3.87	40.0	21.0	59.2	1.41	1360
89-90	5	50	8.49	0.7	550	1.84	0.41	0.46	1.06	77.6	7.40	100	16.3	29	22.9	1.7	4.07	40.5	20.0	58.6	1.44	1360
90-91	3	40	8.48	0.6	560	2.18	0.38	0.42	1.11	78.1	7.42	101	16.7	29	24.1	1.7	3.92	40.5	19.0	61.2	1.46	1340
91-92	2	60	8.15	0.6	500	1.98	0.38	0.46	1.10	76.1	7.29	97	14.7	29	22.8	1.6	3.73	40.0	19.0	59.4	1.42	1350
92-93	3	50	8.09	1.5	520	1.97	0.39	0.46	1.07	73.4	7.26	96	16.8	27	23.2	1.8	3.86	40.5	20.0	56.2	1.38	1405
93-94	1	50	7.92	0.9	530	1.96	0.40	0.52	1.18	73.7	6.96	92	16.4	26	21.9	1.7	3.74	40.0	20.0	54.4	1.41	1430
94-95	0.5	40	8.07	1.9	530	1.80	0.44	0.58	1.13	78.3	7.21	93	17.4	28	22.6	1.8	3.94	42.0	21.5	57.2	1.40	1630
95-96	1	40	8.49	0.9	580	2.15	0.45	0.62	1.10	79.5	7.31	101	21.2	31	24.0	1.8	4.18	42.5	22.0	60.6	1.45	1470

Table 14 continued

Depth cm	As ppm	Hg ppb	Al %	Sb ppm	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ca %	Ce ppm	Cs ppm	Cr ppm	Co ppm	Cu ppm	Ga ppm	Ge ppm	Fe %	La ppm	Pb ppm	Li ppm	Mg %	Mn ppm
96-97	2	40	8.66	3.2	596	2.11	0.43	0.54	1.09	77.2	7.43	97	15.9	28	22.8	1.7	4.10	42.0	21.0	58.6	1.48	1385
97-98	3	40	8.43	0.5	550	1.95	0.42	0.50	1.06	78.6	7.70	97	15.9	27	23.6	1.7	3.99	43.0	20.5	58.9	1.43	1290
98-99	3	40	8.40	0.5	530	2.49	0.40	0.48	1.03	73.9	7.52	99	17.1	30	23.0	1.7	4.07	40.5	19.5	60.2	1.44	1270
99-100	3	40	8.39	0.5	540	2.08	0.39	0.48	1.08	76.2	7.69	99	18.9	28	24.4	1.8	4.03	41.5	20.0	62.7	1.43	1235
100-101	3	20	8.34	0.4	530	2.23	0.40	0.44	1.02	74.1	7.66	99	20.1	28	24.1	1.8	4.10	40.0	19.0	62.6	1.42	1200
101-102	3	30	8.69	0.4	530	2.27	0.38	0.46	1.08	74.0	7.68	102	20.7	29	25.1	1.8	4.21	40.0	19.0	63.1	1.49	1255
102-103	0.5	30	8.28	0.4	500	2.06	0.38	0.44	1.08	70.2	7.30	99	15.9	28	23.5	1.7	3.98	38.0	19.0	59.6	1.42	1205
103-104	1	50	8.53	0.4	540	2.41	0.39	0.44	1.09	77.0	7.76	101	16.3	30	24.3	1.8	3.95	41.0	19.0	60.5	1.47	1250
104-105	6	50	8.10	0.7	500	1.95	0.39	0.46	1.04	76.5	7.28	97	15.3	28	22.3	0.9	3.85	40.0	20.5	56.6	1.39	1145
105-106	3	40	8.41	0.7	520	1.84	0.39	0.38	1.03	73.8	7.80	106	15.7	27	23.7	1.7	3.93	39.0	19.5	61.4	1.42	1235
106-107	2	40	8.32	0.7	520	2.03	0.44	0.44	1.04	74.1	7.67	102	17.5	29	24.5	1.7	4.02	39.0	19.0	62.8	1.41	1245
107-108	0.5	40	8.19	0.7	490	1.93	0.37	0.42	1.05	70.8	7.29	98	15.9	29	23.3	1.7	3.86	37.0	18.0	61.2	1.41	1225
108-109	0.5	40	9.03	1.0	570	2.12	0.43	0.42	1.13	71.5	7.76	105	17.4	28	23.6	1.8	4.27	40.0	19.0	57.4	1.55	1305
109-110	0.5	40	8.67	2.8	560	1.96	0.40	0.44	1.09	71.2	7.61	100	16.6	31	23.4	1.7	4.16	39.5	22.0	59.8	1.50	1290
110-111	0.5	30	8.44	1.1	530	2.41	0.46	0.42	1.09	74.0	7.91	101	17.2	28	23.6	1.8	4.12	40.5	20.5	63.0	1.46	1230
111-112	0.5	40	8.69	0.9	570	1.95	0.42	0.44	1.10	75.2	7.71	101	17.4	27	23.7	1.8	4.26	41.0	21.0	59.8	1.49	1255
112-113	2	30	8.74	0.9	506	1.51	0.38	0.46	1.02	70.9	7.16	107	12.7	29	23.1	1.7	4.13	38.7	20.1	57.6	1.47	1215
113-114	1	40	8.84	0.8	580	2.10	0.41	0.46	0.99	77.1	8.05	100	18.1	27	23.9	1.7	4.23	42.5	20.0	61.6	1.47	1200
114-115	3	30	8.33	0.5	550	2.24	0.40	0.54	1.06	77.7	7.57	97	17.7	27	23.7	1.7	3.91	42.0	20.0	60.3	1.40	1130
115-116	3	40	8.51	0.6	550	2.33	0.40	0.58	1.12	74.5	7.64	99	16.5	29	23.8	1.8	3.99	40.0	20.0	60.4	1.49	1185
116-117	3	40	8.14	0.5	500	2.28	0.39	0.50	1.12	70.5	7.41	98	16.7	28	23.5	1.8	3.71	38.5	18.5	58.3	1.48	1170
117-118	3	30	8.53	0.4	520	2.32	0.41	0.50	1.20	72.7	7.53	101	21.1	28	24.4	1.8	3.97	39.0	19.0	63.0	1.53	1180
118-119	0.5	40	8.35	0.4	530	2.36	0.39	0.48	1.04	75.1	7.55	99	18.3	27	24.1	1.8	3.87	39.5	20.0	62.5	1.40	1130
119-120	0.5	40	8.35	0.4	510	2.11	0.41	0.48	1.00	76.6	7.52	102	17.5	30	23.9	1.7	3.77	41.0	20.0	61.0	1.37	1370
120-121	6	40	8.50	0.7	540	2.10	0.42	0.46	0.96	78.6	8.04	102	16.1	29	22.7	1.7	4.04	41.5	20.5	57.9	1.39	1625
121-122	5	30	8.63	0.7	550	2.14	0.40	0.44	0.98	75.7	7.81	113	15.5	28	24.1	1.7	4.11	40.0	20.0	60.2	1.41	1165
122-123	2	50	8.59	0.7	550	2.18	0.38	0.42	0.97	73.3	7.37	101	14.7	30	23.3	1.7	3.97	38.5	18.5	61.2	1.40	1185
123-124	0.5	40	8.49	0.8	540	2.18	0.38	0.46	1.00	76.1	7.74	103	15.5	31	24.5	1.8	3.85	40.0	19.0	63.2	1.40	1210
124-125	1	40	8.57	1.2	550	2.07	0.41	0.46	1.10	71.2	7.71	100	18.6	28	23.5	1.7	4.10	39.5	20.0	58.6	1.47	1210
125-126	0.5	40	8.16	0.9	500	2.16	0.38	0.44	1.08	69.0	7.46	97	17.8	27	22.8	1.7	3.84	38.5	19.5	58.0	1.41	1205
126-127	0.5	40	8.42	0.9	540	2.06	0.40	0.44	1.10	74.2	7.61	100	17.4	28	24.1	1.7	4.02	41.0	20.0	62.4	1.45	1165
127-128	0.5	30	8.54	1.0	530	2.15	0.41	0.40	1.14	71.0	7.46	99	17.4	27	22.9	1.7	4.12	38.5	20.5	59.6	1.52	1225

Table 14 continued

Depth cm	As ppm	Hg ppb	Al %	Sb ppm	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ca %	Ce ppm	Cs ppm	Cr ppm	Co ppm	Cu ppm	Ga ppm	Ge ppm	Fe %	La ppm	Pb ppm	Li ppm	Mg %	Mn ppm
128-129	3	40	8.39	1.4	476	1.86	0.43	0.48	1.27	75.0	7.51	96	14.7	26	23.8	1.8	3.97	40.2	21.6	59.6	1.58	1235
129-130	3	50	7.76	0.9	500	1.90	0.40	0.50	1.30	71.9	7.26	108	16.7	24	22.3	1.5	3.72	39.5	19.5	58.2	1.47	1155
130-131	3	40	8.60	0.5	540	1.79	0.39	0.46	1.42	70.6	7.38	99	16.3	27	22.5	1.6	3.95	38.5	18.5	59.0	1.67	1280
131-132	2	40	8.07	1.9	510	2.39	0.41	0.52	1.26	72.4	7.44	95	18.3	26	23.2	1.8	3.97	39.5	32.5	60.1	1.53	1200
132-133	3	30	8.14	0.4	540	1.73	0.37	0.54	1.24	71.6	6.96	93	16.9	26	22.1	1.6	3.95	38.0	19.0	57.2	1.52	1180
133-134	3	40	7.88	0.4	480	2.02	0.37	0.52	1.24	70.7	6.98	93	17.7	26	23.4	1.7	3.77	38.5	19.0	58.3	1.46	1125
134-135	0.5	40	8.21	0.3	530	2.16	0.37	0.48	1.22	70.3	6.90	99	17.1	29	22.7	1.6	3.99	37.0	18.5	58.2	1.49	1180
135-136	2	40	8.60	0.4	550	2.36	0.40	0.54	1.19	76.2	7.62	101	17.9	28	24.2	1.8	4.00	40.5	20.5	62.5	1.54	1210
136-137	5	50	8.61	0.7	540	2.00	0.40	0.46	1.21	75.6	7.89	104	16.7	30	22.5	1.6	4.12	40.0	20.0	56.0	1.53	1260
137-138	5	30	8.75	0.7	540	2.04	0.39	0.48	1.24	77.6	7.71	105	16.7	29	24.0	1.7	4.12	40.5	19.5	59.8	1.58	1250
138-139	3	40	8.43	0.7	530	1.99	0.37	0.42	1.24	74.6	7.53	100	15.7	28	23.8	1.6	3.89	39.0	19.0	60.8	1.55	1170
139-140	0.5	40	8.52	0.7	530	2.28	0.38	0.40	1.16	74.3	7.75	100	16.1	29	24.4	1.7	3.86	39.0	19.0	62.2	1.50	1175
140-141	0.5	40	8.46	0.9	520	2.02	0.37	0.46	1.18	70.3	7.41	97	17.4	29	22.8	1.7	4.02	39.5	20.0	57.4	1.51	1120
141-142	0.5	40	8.32	1.8	530	1.91	0.42	0.46	1.18	71.8	7.41	100	17.4	28	23.0	1.7	3.94	39.5	20.0	57.6	1.48	1115
142-143	0.5	30	7.31	1.1	490	2.21	0.42	0.50	1.01	76.8	7.61	87	18.0	26	23.6	1.7	3.61	42.0	21.5	61.8	1.30	1000
143-144	0.5	30	8.26	2.4	510	2.45	0.47	0.52	1.10	74.8	7.61	98	18.2	28	23.8	1.7	4.01	41.0	21.5	60.4	1.44	1105
144-145	3	40	8.32	0.9	550	2.14	0.41	0.46	1.14	74.7	7.61	99	20.6	28	23.4	1.7	4.04	40.0	20.0	62.0	1.45	1205
145-146	2	30	8.99	1.1	526	1.61	0.41	0.50	1.27	77.9	7.76	101	15.3	28	23.4	1.7	4.23	41.2	21.1	61.4	1.66	1260
146-147	2	40	9.18	0.7	526	1.95	0.39	0.48	1.30	71.9	7.36	105	16.9	28	22.6	1.6	4.28	40.0	19.5	58.9	1.69	1295
14-148	1	40	8.23	0.5	520	2.14	0.39	0.48	1.30	73.1	7.58	92	16.1	27	23.6	1.7	3.77	40.5	19.5	60.0	1.54	1120
148-149	3	40	8.33	0.5	530	2.14	0.40	0.46	1.31	71.9	7.45	99	17.1	27	23.1	1.7	3.91	39.5	26.0	60.9	1.57	1175
149-150	3	30	8.12	0.4	500	2.03	0.39	0.46	1.33	72.2	7.22	95	17.1	27	23.1	1.7	3.79	39.5	19.0	57.9	1.56	1135
150-151	4	30	8.06	0.4	500	2.07	0.37	0.44	1.28	71.1	7.19	96	18.7	28	23.2	1.7	3.88	38.5	19.0	59.8	1.53	1130
151-152	0.5	40	8.12	0.4	530	2.31	0.40	0.44	1.30	74.1	7.45	96	16.1	27	23.9	1.7	3.98	39.5	19.0	59.5	1.57	1175
152-153	1	30	8.18	0.3	510	2.26	0.39	0.44	1.29	77.7	7.57	99	14.5	28	24.1	1.7	3.79	41.5	19.5	59.6	1.52	1145
153-154	5	40	8.86	0.8	570	1.90	0.44	0.42	1.24	80.9	8.19	108	16.5	29	23.6	1.7	4.25	43.0	21.0	57.9	1.59	1185
154-155	3	50	8.68	0.7	550	2.19	0.41	0.46	1.14	82.5	7.81	103	21.9	29	24.4	1.8	4.20	43.0	21.0	60.8	1.49	1115
155-156	1	40	8.62	0.7	550	1.94	0.38	0.46	1.25	79.5	7.58	99	16.7	29	24.4	1.7	4.10	41.5	20.5	60.8	1.55	1115
156-157	0.5	40	8.59	0.6	540	1.83	0.40	0.46	1.34	77.7	7.15	101	16.5	29	23.8	1.6	3.96	40.0	22.0	60.8	1.63	1195
157-158	0.5	50	8.32	3.1	530	2.02	0.43	0.50	1.41	73.8	7.46	97	19.0	28	23.7	1.7	3.94	42.0	21.5	59.2	1.62	1180
158-159	0.5	30	8.64	0.9	570	2.06	0.45	0.40	1.30	74.1	7.21	100	16.6	28	22.4	1.7	4.16	40.5	20.0	56.2	1.60	1195
159-160	0.5	40	8.76	1.0	550	2.06	0.41	0.44	1.20	77.6	7.66	103	17.4	30	24.1	1.7	4.28	42.5	22.0	61.6	1.56	1140

Table 14 continued

Depth cm	As ppm	Hg ppb	Al %	Sb ppm	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ca %	Ce ppm	Cs ppm	Cr ppm	Co ppm	Cu ppm	Ga ppm	Ge ppm	Fe %	La ppm	Pb ppm	Li ppm	Mg %	Mn ppm
160-161	0.5	50	8.26	0.9	520	2.00	0.40	0.46	1.23	71.9	7.21	97	16.0	30	22.1	1.6	4.02	39.0	19.5	56.2	1.52	1065
161-162	3	50	8.62	0.9	560	1.94	0.40	0.48	1.22	76.5	7.56	100	19.6	29	23.7	1.8	4.09	41.5	21.5	60.4	1.55	1170
Mean	2	47	8.40	0.8	526	2.08	0.41	0.48	1.12	74.5	7.48	100	17.1	28	23.4	1.7	4.01	40.0	20.9	59.5	1.46	1220
St.Dev.	1.79	18.29	0.29	0.59	24.49	0.20	0.03	0.05	0.10	2.60	0.23	4.28	1.39	1.78	0.67	0.09	0.15	1.32	2.73	1.88	0.07	104

Table 14 continued

Depth	Mo	Ni	Nb	P	K	Rb	Ag	Na	Sr	Ta	Te	Tl	Th	Ti	W	U	V	Y	Zn
cm	ppm	ppm	ppm	ppm	%	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm
0-1	0.8	53.2	12.3	1070	1.86	105.3	0.65	0.71	133.0	0.96	0.15	0.72	15.4	0.34	1.2	3.2	195	20.1	142
1-2	0.8	48.7	11.9	1020	2.15	119.2	0.65	0.66	130.2	0.86	0.15	0.68	14.4	0.33	1.1	3.0	197	19.5	139
2-3	0.8	45.4	12.5	1060	2.17	126.6	0.70	0.64	136.9	0.86	0.15	0.72	14.6	0.33	1.1	3.0	197	20.9	135
3-4	1.0	50.8	12.1	1070	2.17	121.0	0.65	0.66	134.6	0.81	0.10	0.64	13.6	0.33	1.1	2.8	201	19.8	138
4-5	0.8	50.0	12.1	1070	2.20	120.9	0.70	0.62	138.3	0.76	0.15	0.64	13.4	0.34	1.0	2.8	209	19.8	144
5-6	1.0	50.3	12.7	1090	2.00	114.8	0.65	0.70	139.6	0.86	0.10	0.66	14.2	0.34	1.2	3.0	199	20.6	143
6-7	0.8	48.3	12.7	970	2.12	114.7	0.65	0.70	135.3	0.86	0.15	0.66	13.8	0.35	1.1	2.8	202	20.2	137
7-8	0.8	49.5	12.7	910	2.09	119.1	0.65	0.69	137.0	0.88	0.15	0.72	15.0	0.34	1.3	3.0	188	20.5	136
8-9	0.8	46.0	11.9	940	2.01	109.5	0.70	0.68	132.7	0.88	0.10	0.68	14.0	0.33	1.2	3.0	200	19.6	134
9-10	1.0	45.8	13.1	880	1.87	112.9	0.70	0.66	128.9	0.88	0.10	0.70	14.2	0.33	1.3	3.2	183	20.6	131
10-11	0.8	49.3	12.9	880	2.20	116.3	0.70	0.73	132.1	0.88	0.05	0.70	14.0	0.36	1.3	3.2	194	20.5	139
11-12	0.8	49.6	12.5	870	2.02	111.7	0.70	0.70	132.3	0.83	0.10	0.66	13.4	0.34	1.2	3.0	199	20.2	140
12-13	1.0	46.9	12.6	850	2.11	114.1	0.65	0.66	130.0	0.79	0.15	0.72	14.1	0.32	2.4	3.2	197	19.3	137
13-14	0.8	48.7	12.2	790	2.02	114.0	0.65	0.64	131.7	0.79	0.10	0.70	14.1	0.32	1.5	3.2	199	19.6	133
14-15	1.2	48.1	13.0	780	2.07	109.9	0.65	0.67	131.9	0.84	0.15	0.70	14.1	0.34	2.1	3.4	201	19.7	134
15-16	2.0	49.9	13.2	750	2.09	117.3	0.65	0.67	134.6	0.89	0.05	0.74	15.3	0.34	1.5	3.4	202	20.5	134
16-17	1.0	54.6	12.1	740	1.74	103.9	0.60	0.69	133.5	0.91	0.15	0.70	15.2	0.34	1.2	3.4	198	20.4	132
17-18	1.0	53.2	12.5	780	2.16	115.7	0.55	0.70	136.2	0.91	0.10	0.66	14.2	0.35	1.2	3.0	205	20.2	141
18-19	1.0	48.2	12.1	680	1.82	111.1	0.55	0.64	127.4	0.86	0.10	0.66	14.0	0.33	1.1	2.8	185	20.4	125
19-20	0.8	46.3	12.7	690	1.90	115.5	0.55	0.63	134.6	0.86	0.15	0.66	14.0	0.33	1.1	3.0	197	20.6	126
20-21	0.8	48.1	12.7	720	2.20	128.4	0.55	0.63	138.3	0.81	0.05	0.70	14.4	0.33	1.0	2.8	204	20.9	132
21-22	1.0	54.1	12.1	700	2.09	117.3	0.55	0.66	133.0	0.81	0.10	0.66	13.6	0.34	1.1	2.8	198	20.3	127
22-23	0.8	50.6	12.7	700	2.18	121.7	0.55	0.67	132.7	0.86	0.05	0.72	14.6	0.34	1.1	2.8	193	20.7	125
23-24	0.8	52.6	13.3	710	2.02	117.6	0.95	0.71	138.4	0.88	0.15	0.72	15.2	0.37	1.2	3.0	206	21.1	130
24-25	0.8	51.9	12.5	690	2.06	109.6	0.55	0.70	129.2	0.93	0.15	0.70	14.4	0.35	1.2	3.0	194	20.5	126
25-26	0.8	51.3	12.3	670	1.91	111.0	0.60	0.68	128.4	0.88	0.10	0.70	14.0	0.35	1.2	2.8	201	20.2	131
26-27	0.8	47.9	12.9	700	2.15	115.4	0.55	0.72	135.1	0.83	0.15	0.68	13.8	0.36	1.2	2.8	201	20.6	127
27-28	0.8	48.7	12.7	670	2.11	114.3	0.70	0.71	132.8	0.83	0.05	0.68	13.6	0.35	1.2	2.6	199	20.6	126
28-29	1.4	46.7	12.6	680	1.85	105.2	0.50	0.66	128.0	0.84	0.15	0.66	13.7	0.33	3.5	2.8	197	19.1	124
29-30	5.2	47.9	13.6	680	1.92	109.6	0.65	0.66	131.2	0.89	0.10	0.70	14.1	0.35	1.9	3.0	197	20.2	123
30-31	1.2	46.3	12.8	660	1.86	103.0	0.70	0.66	128.9	0.84	0.15	0.66	13.3	0.34	1.5	2.8	201	18.9	125
31-32	1.8	46.5	13.0	680	2.11	112.4	0.50	0.66	133.6	0.84	0.05	0.70	13.9	0.34	1.4	2.8	207	19.4	126

Table 14 continued

Depth cm	Mo ppm	Ni ppm	Nb ppm	P ppm	K %	Rb ppm	Ag ppm	Na %	Sr ppm	Ta ppm	Te ppm	Tl ppm	Th ppm	Ti %	W ppm	U ppm	V ppm	Y ppm	Zn ppm
32-33	0.8	54.1	13.1	690	1.26	67.8	0.55	0.73	138.5	0.96	0.10	0.72	14.4	0.37	1.2	2.8	203	20.4	124
33-34	0.8	50.3	12.5	700	2.27	121.8	0.50	0.70	137.2	0.86	0.10	0.68	14.4	0.36	1.1	2.8	207	20.1	127
34-35	0.8	47.0	12.9	690	2.00	109.2	0.50	0.69	133.4	0.91	0.15	0.64	13.8	0.35	1.1	2.8	189	20.1	121
35-36	0.8	46.6	13.1	690	2.19	118.6	0.60	0.70	137.6	0.86	0.10	0.68	13.8	0.35	1.1	2.6	203	20.9	126
36-37	0.8	49.2	12.9	710	2.28	125.0	0.60	0.69	139.3	0.86	0.10	0.66	14.0	0.35	1.1	2.6	210	21.0	128
37-38	0.8	46.9	12.9	670	1.85	116.9	0.50	0.68	136.0	0.91	0.10	0.64	13.8	0.33	1.1	2.6	199	20.9	121
38-39	0.8	51.3	12.3	690	2.22	121.8	0.50	0.69	139.2	0.86	0.15	0.66	14.4	0.34	1.1	2.6	201	20.8	129
39-40	0.8	42.9	12.1	560	1.66	109.2	0.65	0.56	119.4	0.86	0.10	0.62	13.8	0.28	1.1	2.6	168	19.7	104
40-41	0.8	47.9	12.5	680	2.08	104.6	0.75	0.71	128.6	0.83	0.10	0.66	13.2	0.37	1.2	2.6	204	19.5	126
41-42	0.8	50.7	11.9	690	1.89	104.0	0.65	0.66	129.3	0.83	0.05	0.66	13.0	0.35	1.2	2.6	201	19.4	125
42-43	1.0	49.6	13.1	660	2.10	112.4	0.55	0.69	132.1	0.88	0.05	0.70	13.4	0.35	1.3	2.6	199	20.6	125
43-44	0.8	44.6	12.9	650	2.00	108.3	0.60	0.66	129.8	0.83	0.05	0.66	13.2	0.35	1.3	2.6	201	20.3	122
44-45	1.8	48.8	13.4	680	2.14	118.2	0.50	0.63	134.0	0.89	0.15	0.74	14.3	0.34	4.0	3.0	210	20.3	126
45-46	1.4	47.8	13.8	700	2.02	112.1	0.80	0.67	132.2	0.94	0.05	0.76	14.1	0.34	1.6	3.0	205	20.3	125
46-47	2.2	50.3	13.8	680	2.01	110.5	0.50	0.66	130.4	0.94	0.05	0.72	13.9	0.35	1.6	3.0	206	19.9	127
47-48	2.2	59.0	13.2	640	1.97	107.4	0.45	0.62	128.1	0.84	0.15	0.68	13.1	0.33	1.7	2.8	196	19.3	120
48-49	1.0	52.1	13.1	670	2.05	109.5	0.50	0.73	131.4	0.96	0.15	0.70	14.0	0.37	1.3	2.8	199	20.3	122
49-50	1.0	47.6	12.3	650	2.19	122.9	0.55	0.61	127.7	0.86	0.05	0.68	14.4	0.34	1.1	2.6	203	20.3	119
50-51	1.0	49.1	13.5	690	2.11	112.3	0.55	0.70	131.9	0.91	0.10	0.66	13.8	0.37	1.2	2.8	203	20.3	125
51-52	0.8	46.6	12.5	640	2.09	119.2	0.50	0.64	129.6	0.86	0.15	0.66	13.4	0.33	1.1	2.6	196	20.2	118
52-53	0.8	45.8	13.3	680	2.05	115.1	0.55	0.66	131.3	0.91	0.15	0.66	13.4	0.35	1.1	2.6	196	20.8	124
53-54	0.8	46.5	13.3	710	1.97	113.5	0.55	0.71	136.5	0.86	0.10	0.64	14.0	0.35	1.2	2.6	214	20.4	131
54-55	0.8	50.5	13.3	700	1.90	117.9	1.10	0.69	137.2	0.91	0.10	0.70	14.6	0.34	1.2	2.8	200	21.4	131
55-56	1.0	53.1	13.3	710	2.05	119.3	0.55	0.68	138.9	0.91	0.10	0.70	15.0	0.35	1.2	2.8	212	21.2	134
56-57	1.0	60.0	12.7	700	2.10	111.2	0.50	0.67	131.6	0.88	0.05	0.72	14.0	0.36	1.3	2.6	200	20.3	124
57-58	0.8	52.2	13.1	750	2.07	112.1	0.60	0.68	136.3	0.88	0.10	0.72	14.0	0.37	1.3	2.8	200	20.6	125
58-59	0.8	51.3	12.7	790	1.99	106.5	0.55	0.68	129.5	0.83	0.10	0.68	13.2	0.36	1.2	2.6	204	19.9	127
59-60	0.8	52.2	12.7	990	1.93	108.9	0.70	0.71	136.2	0.83	0.10	0.66	13.8	0.35	1.2	2.6	211	20.4	130
60-61	2.2	47.0	13.4	890	1.91	111.3	0.50	0.68	133.9	0.84	0.20	0.70	13.9	0.36	3.1	2.8	207	19.5	124
61-62	1.2	46.6	13.0	750	2.10	112.7	0.50	0.70	134.2	0.89	0.10	0.70	14.3	0.36	1.6	3.0	209	19.5	127
62-63	0.8	47.2	13.0	690	1.93	108.6	0.50	0.64	130.4	0.89	0.10	0.70	13.3	0.34	1.8	2.8	213	19.0	129
63-64	2.2	49.7	12.8	660	2.04	108.5	0.50	0.65	126.1	0.84	0.15	0.68	12.7	0.33	3.5	2.6	202	18.6	124

Table 14 continued

Depth cm	Mo ppm	Ni ppm	Nb ppm	P ppm	K %	Rb ppm	Ag ppm	Na %	Sr ppm	Ta ppm	Te ppm	Tl ppm	Th ppm	Ti %	W ppm	U ppm	V ppm	Y ppm	Zn ppm
64-65	0.8	53.3	12.7	700	2.12	115.5	0.55	0.74	130.9	0.96	0.15	0.72	14.4	0.37	1.2	2.8	207	19.4	126
65-66	0.8	46.6	13.1	690	2.16	116.9	0.55	0.71	132.1	0.91	0.15	0.70	14.2	0.37	1.2	2.6	208	20.4	125
66-67	0.8	48.7	12.5	680	1.95	112.3	0.50	0.65	128.3	0.86	0.10	0.64	13.2	0.35	1.1	2.4	201	19.6	125
67-68	0.6	46.8	12.9	670	1.96	109.7	0.55	0.66	135.6	0.91	0.10	0.64	13.2	0.37	1.2	2.6	205	20.5	126
68-69	0.8	45.4	13.1	680	2.10	115.1	0.60	0.71	135.8	0.91	0.10	0.64	13.6	0.36	1.2	2.6	203	20.2	126
69-70	0.8	50.1	12.9	730	1.95	108.0	0.70	0.68	139.5	0.86	0.05	0.64	13.4	0.35	1.1	2.6	205	20.2	133
70-71	0.8	54.1	12.7	690	1.95	111.9	0.55	0.68	135.2	0.86	0.05	0.66	14.0	0.34	1.1	2.6	206	20.9	125
71-72	0.8	47.5	12.9	680	2.09	115.8	0.50	0.72	131.9	0.86	0.10	0.68	13.6	0.35	1.1	2.6	188	20.8	122
72-73	0.8	51.5	11.9	680	1.99	103.7	0.50	0.68	130.1	0.83	0.05	0.66	13.4	0.36	1.3	2.6	200	19.3	124
73-74	0.8	48.7	12.9	690	2.14	114.1	0.55	0.70	134.3	0.93	0.10	0.72	14.0	0.36	1.3	2.8	204	20.6	127
74-75	0.8	49.0	13.1	680	2.11	111.5	0.55	0.71	133.5	0.88	0.10	0.72	13.6	0.36	1.2	2.6	203	20.5	123
75-76	1.0	48.8	13.1	690	2.13	113.9	0.65	0.72	135.2	0.88	0.05	0.70	13.6	0.35	1.2	2.8	206	20.7	128
76-77	1.6	48.6	13.2	740	2.08	118.3	0.55	0.67	132.4	0.84	0.20	0.70	14.3	0.35	2.6	2.8	198	20.2	118
77-78	1.6	46.6	13.2	680	1.90	105.2	0.50	0.69	131.6	0.89	0.15	0.66	13.7	0.35	1.6	2.8	195	19.5	123
78-79	1.0	50.6	14.0	700	2.02	112.1	0.55	0.72	137.3	0.99	0.10	0.74	14.5	0.36	1.6	3.0	200	20.8	127
79-80	1.4	50.8	13.2	670	1.94	107.5	0.50	0.69	133.6	0.79	0.10	0.66	13.5	0.35	1.5	2.6	193	20.0	126
80-81	1.0	52.3	12.5	690	2.12	111.6	0.55	0.75	131.4	0.96	0.15	0.72	14.6	0.36	1.2	2.6	196	19.9	120
81-82	1.0	49.5	12.7	730	1.99	112.0	0.55	0.74	135.1	0.96	0.10	0.66	14.6	0.35	1.1	2.6	194	20.6	123
82-83	0.8	48.0	12.5	720	1.96	105.4	0.55	0.71	142.3	0.86	0.10	0.64	13.4	0.37	1.1	2.6	195	20.4	125
83-84	0.8	48.7	13.1	720	1.91	108.3	0.55	0.70	141.5	0.86	0.05	0.64	13.6	0.35	1.1	2.6	198	20.8	120
84-85	0.8	44.5	13.3	730	2.05	112.7	0.55	0.71	137.7	0.86	0.15	0.66	13.6	0.34	1.2	2.6	192	21.0	120
85-86	0.8	49.2	13.1	700	2.10	113.6	0.50	0.70	141.4	0.81	0.15	0.68	13.4	0.34	1.1	2.6	195	21.2	123
86-87	0.8	49.0	12.5	690	1.91	108.0	0.50	0.66	137.7	0.81	0.10	0.62	13.2	0.33	1.1	2.6	195	20.0	119
87-88	0.8	52.0	13.3	700	2.07	120.4	0.65	0.71	138.9	0.86	0.15	0.66	14.2	0.35	1.1	2.6	200	21.4	128
88-89	0.8	54.0	12.5	700	1.76	100.8	0.50	0.71	134.1	0.88	0.05	0.68	14.4	0.35	1.2	2.8	191	20.3	122
89-90	0.8	51.8	12.5	720	1.80	104.2	0.60	0.72	139.8	0.88	0.10	0.66	14.4	0.35	1.3	2.6	195	20.9	123
90-91	0.8	51.4	12.9	740	2.20	112.1	0.60	0.73	134.0	0.88	0.05	0.74	13.8	0.36	1.3	2.6	198	20.8	125
91-92	0.8	45.8	12.7	780	1.87	104.5	0.55	0.72	134.2	0.83	0.10	0.68	13.8	0.36	1.2	2.6	193	20.4	120
92-93	2.0	47.0	13.4	870	1.97	110.9	0.55	0.70	136.9	0.84	0.25	0.70	14.1	0.35	3.1	2.8	195	20.0	120
93-94	0.8	44.4	12.6	870	1.86	102.3	0.50	0.71	137.1	0.84	0.15	0.66	13.7	0.33	2.8	2.8	187	19.7	115
94-95	2.0	47.2	13.8	1090	1.95	106.2	0.50	0.72	138.3	0.94	0.15	0.68	14.3	0.35	3.8	2.8	194	20.6	117
95-96	1.2	54.9	14.4	770	2.04	111.6	0.55	0.73	145.0	0.89	0.10	0.70	14.1	0.37	1.7	2.8	202	21.3	128

Table 14 continued

Depth cm	Mo ppm	Ni ppm	Nb ppm	P ppm	K %	Rb ppm	Ag ppm	Na %	Sr ppm	Ta ppm	Te ppm	Tl ppm	Th ppm	Ti %	W ppm	U ppm	V ppm	Y ppm	Zn ppm
96-97	0.8	52.3	12.5	770	2.22	119.1	0.55	0.74	138.9	0.91	0.05	0.70	15.0	0.37	1.2	2.8	201	20.0	120
97-98	0.8	47.3	12.9	690	2.26	125.0	0.55	0.67	135.6	0.96	0.05	0.72	15.2	0.37	1.2	2.8	199	20.8	121
98-99	0.8	50.2	12.7	700	1.94	109.4	0.60	0.67	133.8	0.91	0.10	0.66	14.0	0.36	1.2	2.6	203	20.0	125
99-100	1.0	49.5	13.1	690	2.18	122.3	0.55	0.72	139.5	0.91	0.15	0.72	14.4	0.36	1.1	2.8	200	20.9	124
100-101	1.0	53.8	13.1	680	2.02	114.2	0.55	0.66	134.2	0.86	0.05	0.66	13.8	0.35	1.1	2.6	201	20.4	126
101-102	1.0	53.0	12.9	690	1.96	114.6	0.50	0.72	137.4	0.86	0.05	0.64	14.0	0.36	1.1	2.8	210	20.7	131
102-103	0.8	47.3	12.3	690	1.89	106.5	0.55	0.66	128.6	0.81	0.10	0.62	13.0	0.34	1.0	2.6	205	19.5	125
103-104	0.8	46.5	13.1	690	2.15	125.4	0.55	0.68	137.8	0.91	0.10	0.70	14.2	0.35	1.1	2.6	204	20.9	132
104-105	0.8	46.8	13.1	650	1.17	65.7	0.50	0.66	130.1	0.98	0.15	0.70	14.6	0.35	1.4	2.8	194	20.2	122
105-106	0.8	53.2	12.5	670	1.87	107.3	0.55	0.67	127.8	0.88	0.10	0.70	13.8	0.35	1.3	2.8	202	19.9	123
106-107	1.0	53.3	12.9	690	2.03	112.7	0.60	0.68	127.5	0.83	0.10	0.76	13.8	0.35	1.3	2.8	202	20.5	131
107-108	0.8	51.1	12.1	650	1.81	102.6	0.55	0.66	125.2	0.78	0.05	0.64	13.0	0.35	1.2	2.6	193	19.1	126
108-109	1.2	47.9	13.2	730	2.22	120.5	0.50	0.67	134.9	0.84	0.15	0.70	13.9	0.37	3.2	2.8	221	19.6	132
109-110	1.4	47.0	13.4	710	2.03	110.9	0.65	0.69	130.1	0.89	0.10	0.72	14.1	0.35	1.7	3.0	209	19.3	127
110-111	1.2	48.8	13.8	680	2.07	114.3	0.50	0.69	131.3	0.99	0.15	0.74	14.3	0.35	3.7	3.0	203	19.7	127
111-112	1.2	49.8	13.8	690	2.04	112.7	0.55	0.70	135.5	0.94	0.05	0.74	14.3	0.36	1.7	3.0	206	19.8	128
112-113	0.6	42.7	12.3	750	2.21	97.9	0.35	0.69	133.1	0.85	0.05	0.66	13.5	0.35	0.9	2.6	202	19.1	132
113-114	1.0	51.1	12.9	690	2.21	128.1	0.65	0.66	138.6	0.91	0.10	0.72	15.0	0.34	1.1	2.8	212	20.8	122
114-115	0.8	48.9	12.9	670	2.19	122.0	0.50	0.71	135.3	0.91	0.15	0.68	14.6	0.37	1.2	2.8	199	20.7	121
115-116	1.0	46.7	13.7	690	2.08	115.4	0.65	0.68	137.5	0.91	0.15	0.68	14.0	0.37	1.2	3.0	209	20.7	125
116-117	1.0	48.5	12.3	670	1.86	114.3	0.55	0.65	130.7	0.81	0.10	0.68	13.4	0.32	1.1	2.6	205	19.7	128
117-118	1.0	51.0	13.5	710	2.01	117.7	0.50	0.69	138.9	0.86	0.15	0.66	13.6	0.35	1.2	2.8	210	21.1	129
118-119	0.8	49.9	12.7	830	2.16	122.1	0.55	0.64	136.1	0.86	0.10	0.94	13.8	0.33	1.1	2.6	199	20.8	125
119-120	0.8	48.0	13.5	1030	1.97	113.0	0.55	0.71	132.8	0.91	0.10	0.68	14.4	0.36	1.2	2.8	197	20.6	128
120-121	0.8	50.5	12.9	1090	2.05	112.9	0.60	0.70	133.5	0.98	0.10	0.76	15.0	0.35	1.3	3.0	201	20.4	124
121-122	1.0	59.0	12.5	870	2.19	117.3	0.60	0.67	133.2	0.88	0.05	0.72	14.2	0.35	1.2	2.8	204	20.4	125
122-123	0.8	48.2	12.3	720	2.03	110.2	0.80	0.69	130.9	0.83	0.05	0.70	13.6	0.35	1.2	2.6	202	19.8	127
123-124	0.8	47.6	13.3	690	2.16	119.6	0.55	0.70	132.7	0.83	0.05	0.72	14.0	0.36	1.2	2.8	201	20.7	130
124-125	1.2	49.1	13.6	690	2.00	114.0	0.55	0.67	129.9	0.89	0.15	0.70	13.9	0.37	2.9	2.8	207	19.8	128
125-126	0.8	48.5	12.6	670	1.73	104.4	0.50	0.65	125.6	0.84	0.05	0.66	13.5	0.33	1.4	2.8	198	19.0	125
126-127	1.0	49.2	13.6	680	2.06	112.8	0.50	0.67	131.3	0.94	0.15	0.72	14.1	0.35	2.2	3.0	205	19.5	125
127-128	1.2	47.2	13.0	680	1.94	107.7	0.45	0.64	130.0	0.84	0.15	0.68	13.3	0.34	1.8	2.8	205	19.0	126

Table 14 continued

Depth cm	Mo ppm	Ni ppm	Nb ppm	P ppm	K %	Rb ppm	Ag ppm	Na %	Sr ppm	Ta ppm	Te ppm	Tl ppm	Th ppm	Ti %	W ppm	U ppm	V ppm	Y ppm	Zn ppm
128-129	0.8	45.0	13.7	700	1.79	86.2	0.50	0.66	135.6	0.90	0.05	0.72	14.5	0.34	1.0	3.0	204	20.6	122
129-130	1.4	51.3	12.5	630	1.15	64.0	0.55	0.62	121.6	0.91	0.05	0.72	13.8	0.33	1.2	2.8	182	19.7	114
130-131	0.8	45.7	12.5	720	2.11	118.1	0.50	0.66	132.8	0.91	0.10	0.64	13.6	0.35	1.1	2.6	205	19.9	127
131-132	1.0	46.2	12.7	680	1.82	111.0	0.60	0.65	132.5	0.91	0.10	0.62	13.6	0.35	1.2	2.6	197	20.3	123
132-133	0.8	46.6	12.5	700	2.04	109.4	0.55	0.66	130.7	0.81	0.15	0.62	13.0	0.34	1.1	2.6	198	20.0	120
133-134	0.8	46.4	12.5	680	1.80	110.3	0.60	0.70	131.9	0.86	0.10	0.60	13.4	0.33	1.1	2.6	188	20.3	118
134-135	0.8	47.6	12.5	720	2.17	107.7	0.50	0.70	133.6	0.86	0.10	0.64	13.0	0.35	1.1	2.6	197	19.4	127
135-136	0.8	49.1	13.1	710	2.15	120.6	0.60	0.68	135.8	0.86	0.15	0.70	14.0	0.35	1.2	2.8	207	20.8	130
136-137	0.8	54.3	12.9	710	2.18	114.0	0.55	0.71	130.5	0.98	0.10	0.74	14.6	0.37	1.4	3.0	202	20.1	128
137-138	0.8	52.9	12.9	720	2.11	111.9	0.60	0.72	134.7	0.93	0.05	0.70	14.2	0.37	1.3	2.8	207	20.5	129
138-139	0.8	46.4	12.9	680	1.87	104.8	0.65	0.61	133.4	0.83	0.05	0.70	13.4	0.35	1.2	2.8	199	20.1	125
139-140	0.8	47.5	13.1	690	1.96	113.2	0.50	0.67	130.6	0.88	0.10	0.70	13.6	0.35	1.3	2.6	201	20.8	128
140-141	2.6	48.3	13.4	700	1.84	106.6	0.55	0.71	133.8	0.84	0.10	0.64	13.9	0.36	1.5	2.8	203	19.4	124
141-142	1.0	48.3	13.0	710	2.04	114.5	0.50	0.70	131.6	0.84	0.20	0.70	14.1	0.33	1.9	2.8	197	19.7	125
142-143	1.0	49.5	14.2	590	1.87	118.4	0.55	0.62	127.8	0.94	0.10	0.74	15.1	0.32	3.7	3.2	177	20.6	109
143-144	2.2	50.8	13.8	680	1.88	108.8	0.55	0.68	133.5	0.89	0.25	0.70	14.3	0.35	4.0	3.0	192	19.8	124
144-145	1.2	52.4	13.6	690	2.13	111.7	0.55	0.67	132.7	0.84	0.05	0.72	13.7	0.35	1.5	2.8	198	20.1	126
145-146	0.8	50.2	13.9	700	1.95	86.2	0.40	0.72	132.6	0.90	0.05	0.70	13.9	0.36	1.0	2.8	205	20.8	128
146-147	1.0	56.5	12.5	710	1.80	93.2	0.50	0.71	136.5	0.91	0.15	0.72	14.2	0.36	1.2	2.8	210	19.5	126
14-148	0.8	44.9	12.1	650	2.21	122.6	0.60	0.64	131.2	0.86	0.05	0.66	14.2	0.35	1.1	2.6	201	19.7	117
148-149	0.8	49.4	12.7	680	2.01	114.0	0.50	0.67	136.9	0.86	0.10	0.64	14.0	0.35	1.2	2.6	198	19.9	123
149-150	0.8	47.0	12.3	680	1.79	106.9	0.50	0.67	132.2	0.81	0.10	0.64	13.6	0.34	1.1	2.6	194	19.9	122
150-151	0.8	48.1	12.7	670	1.87	112.3	0.50	0.67	135.4	0.81	0.05	0.60	13.4	0.33	1.1	2.6	197	20.2	122
151-152	0.8	45.3	12.7	690	2.06	111.7	0.50	0.65	135.6	0.86	0.15	0.66	13.2	0.34	1.1	2.6	200	20.4	123
152-153	0.6	42.8	12.9	680	2.15	123.6	0.55	0.66	136.8	0.86	0.15	0.70	14.2	0.34	1.1	2.6	193	21.0	123
153-154	0.8	57.7	13.5	720	2.21	118.0	0.55	0.76	140.5	0.98	0.15	0.74	15.6	0.37	1.4	3.0	206	21.1	128
154-155	1.0	60.9	13.7	710	2.18	115.4	0.70	0.79	142.2	0.98	0.15	0.76	15.4	0.38	1.3	3.0	197	21.4	126
155-156	0.8	47.4	13.3	670	2.10	114.8	0.55	0.73	143.4	0.88	0.10	0.70	14.4	0.38	1.3	2.8	195	21.0	125
156-157	0.8	50.8	13.1	710	2.03	110.2	0.65	0.73	142.1	0.83	0.10	0.70	13.8	0.37	1.2	2.8	196	21.0	124
157-158	6.6	51.2	14.2	690	2.01	114.1	0.65	0.74	141.8	0.89	0.15	0.70	14.7	0.37	2.6	3.0	195	21.0	122
158-159	1.2	46.1	12.8	690	2.10	112.5	0.50	0.68	138.0	0.79	0.05	0.66	14.3	0.34	3.4	2.8	199	19.4	123
159-160	1.0	48.7	14.2	730	2.07	112.9	0.55	0.75	141.2	0.94	0.10	0.72	14.9	0.37	1.8	3.0	203	20.3	129

Table 14 continued

Depth cm	Mo ppm	Ni ppm	Nb ppm	P ppm	K %	Rb ppm	Ag ppm	Na %	Sr ppm	Ta ppm	Te ppm	Tl ppm	Th ppm	Ti %	W ppm	U ppm	V ppm	Y ppm	Zn ppm
160-161	1.6	46.5	13.0	690	2.03	105.8	0.55	0.70	131.4	0.89	0.05	0.68	13.5	0.35	1.7	2.8	201	18.7	124
161-162	1.6	53.1	14.2	690	2.08	115.7	0.55	0.72	139.2	0.89	0.15	0.72	14.7	0.36	1.6	3.0	202	20.3	124
Mean	1.1	49.4	12.9	732	2.01	111.8	0.57	0.68	133.9	0.88	0.11	0.69	14.0	0.35	1.5	2.8	200	20.2	126
St.Dev.	0.66	3.19	0.51	103	0.17	9.14	0.09	0.03	4.18	0.05	0.04	0.04	0.56	0.01	0.66	0.19	6.83	0.60	5.72

Table 15. Corrected elemental analysis results for Lake Winnipeg 99-900 core 8

Depth cm	As ppm	Hg ppb	Al %	Sb ppm	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ca %	Ce ppm	Cs ppm	Cr ppm	Co ppm	Cu ppm	Ga ppm	Ge ppm	Fe %	La ppm	Pb ppm	Li ppm	Mg %	Mn ppm
0-1	4	90	8.12	1.0	532	2.14	0.34	0.48	1.30	64.4	6.64	98	17.4	28	21.3	1.6	4.04	36.6	26.0	54.4	1.55	875
1-2	4	90	8.38	1.1	545	2.35	0.34	0.50	1.34	66.8	6.89	97	18.4	27	22.4	1.7	4.08	38.6	26.5	56.2	1.55	815
2-3	3	80	8.36	1.0	557	2.21	0.34	0.50	1.35	65.5	6.74	98	18.1	30	22.5	1.6	4.13	37.6	25.5	56.6	1.59	935
3-4	5	90	8.13	1.0	550	2.01	0.34	0.49	1.28	66.7	7.12	101	17.2	27	21.1	1.6	3.91	38.3	26.0	58.0	1.55	970
4-5	6	90	7.70	1.0	532	1.92	0.35	0.55	1.21	65.1	6.52	98	16.4	28	20.8	1.6	3.91	37.3	27.5	55.6	1.44	990
5-6	5	100	8.34	1.0	625	1.93	0.34	0.51	1.33	69.2	6.96	101	17.5	28	21.8	1.5	4.11	38.4	27.0	54.6	1.58	1035
6-7	3	90	8.22	1.0	577	2.14	0.33	0.52	1.29	67.4	6.71	102	17.7	28	21.6	1.5	4.03	37.9	26.0	56.1	1.60	1055
7-8	5	110	8.28	1.1	560	2.15	0.35	0.60	1.30	69.8	6.96	105	18.8	27	22.7	1.6	4.01	38.9	27.0	57.5	1.56	1070
8-9	5	120	8.04	0.9	532	2.26	0.32	0.50	1.25	63.4	6.56	100	17.5	27	21.3	1.5	3.80	35.4	24.5	55.1	1.48	1035
9-10	7	110	8.15	1.0	515	2.07	0.35	0.53	1.28	66.0	6.86	98	18.5	28	22.5	1.6	4.01	38.4	27.0	57.5	1.52	1055
10-11	5	100	8.32	1.0	557	2.33	0.35	0.55	1.30	70.3	7.11	99	19.2	28	22.9	1.7	4.09	40.4	28.0	59.5	1.58	1155
11-12	3	120	8.16	1.0	520	2.19	0.34	0.49	1.28	64.1	6.51	97	18.2	28	21.5	1.5	4.04	36.4	25.5	55.4	1.52	1070
12-13	5	110	8.53	1.0	582	1.90	0.35	0.54	1.32	66.2	6.86	103	17.5	30	22.1	1.6	4.11	38.4	27.5	56.8	1.65	1185
13-14	1	110	8.54	1.1	585	1.95	0.38	0.54	1.30	68.5	6.96	100	17.8	29	22.0	1.5	4.08	39.4	28.5	55.2	1.60	1135
14-15	6	120	8.35	1.0	577	2.01	0.36	0.60	1.27	65.8	6.76	98	17.8	29	21.3	1.5	3.76	37.9	27.0	53.8	1.56	1110
15-16	5	110	8.20	1.1	533	2.24	0.35	0.56	1.24	68.9	6.84	96	18.4	28	22.0	1.6	4.02	39.6	28.5	56.2	1.53	1015
16-17	5	110	8.43	1.1	565	2.10	0.37	0.58	1.38	70.1	6.94	100	19.0	29	22.5	1.6	4.07	40.1	28.5	57.2	1.54	1000
17-18	6	120	8.45	1.0	568	2.30	0.36	0.58	1.24	67.6	6.54	97	19.3	29	22.0	1.7	4.14	38.6	25.5	55.4	1.52	1025
18-19	6	100	8.29	1.1	620	2.36	0.38	0.61	1.20	68.2	6.84	96	20.6	28	23.0	1.8	4.08	38.1	27.0	56.6	1.55	995
19-20	6	70	7.49	1.1	513	2.07	0.38	0.59	1.10	70.3	6.92	94	18.2	27	21.4	1.6	3.55	40.3	26.0	56.4	1.37	935
20-21	6	90	8.38	1.0	615	2.08	0.37	0.57	1.19	73.3	6.86	98	18.7	28	21.9	1.5	4.17	39.9	24.5	55.1	1.51	1090
21-22	1	70	7.99	0.9	608	2.24	0.34	0.52	1.10	69.3	6.56	94	18.7	26	21.3	1.5	4.03	37.9	22.5	54.1	1.45	1060
22-23	5	80	8.40	0.9	610	2.25	0.34	0.54	1.15	73.3	7.01	118	20.2	28	22.6	1.7	4.10	40.9	22.5	57.7	1.48	1055
23-24	4	60	8.14	0.9	583	2.41	0.32	0.50	1.19	69.1	6.76	95	19.3	25	22.2	1.6	4.05	38.9	21.0	56.8	1.50	1065
24-25	3	60	8.33	0.8	595	1.97	0.31	0.49	1.22	65.7	6.51	99	18.5	27	21.3	1.6	4.17	36.9	20.0	55.2	1.53	1125
25-26	3	50	8.18	0.8	588	2.13	0.31	0.45	1.20	68.1	6.61	97	19.0	26	21.6	1.5	4.03	38.4	20.0	56.2	1.49	1120
26-27	1	70	8.25	0.8	580	2.24	0.31	0.49	1.15	68.6	6.71	97	19.4	27	22.5	1.6	4.05	38.9	20.5	58.8	1.48	1105
27-28	3	50	8.31	0.9	573	2.29	0.33	0.48	1.09	70.8	7.01	91	19.7	25	22.7	1.6	4.12	40.4	21.5	59.5	1.40	1105
28-29	1	60	8.36	0.9	605	2.15	0.35	0.52	1.19	69.5	6.96	94	19.7	26	21.7	1.5	4.18	39.9	21.0	55.9	1.51	1190
29-30	3	50	8.38	0.8	618	2.31	0.33	0.48	1.32	65.3	6.96	94	19.7	25	21.4	1.5	4.16	37.4	20.5	53.9	1.61	1200
30-31	1	40	7.98	1.0	584	2.19	0.29	0.46	1.38	66.4	6.54	95	19.7	25	20.8	1.6	3.96	37.1	20.0	54.6	1.58	1150
31-32	0.5	50	8.33	0.9	616	1.99	0.31	0.50	1.40	69.7	6.84	97	19.7	25	21.8	1.6	4.06	39.1	21.0	56.8	1.62	1170

Table 15 continued

Depth cm	As ppm	Hg ppb	Al %	Sb ppm	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ca %	Ce ppm	Cs ppm	Cr ppm	Co ppm	Cu ppm	Ga ppm	Ge ppm	Fe %	La ppm	Pb ppm	Li ppm	Mg %	Mn ppm
32-33	3	40	8.31	0.8	599	2.15	0.30	0.44	1.43	65.1	6.49	92	19.1	24	21.6	1.6	4.03	36.6	19.5	54.0	1.64	1195
33-34	3	40	8.22	0.9	581	2.01	0.32	0.47	1.39	69.0	6.69	95	18.4	26	21.6	1.6	3.88	38.6	20.0	54.6	1.61	1180
34-35	5	50	8.13	0.9	624	1.72	0.33	0.47	1.36	70.3	7.22	95	17.6	25	20.5	1.6	3.80	40.3	21.5	55.4	1.57	1160
35-36	4	50	7.70	0.8	566	1.73	0.30	0.45	1.27	61.8	5.42	137	17.3	28	20.0	1.6	3.80	35.3	20.0	50.4	1.50	1130
36-37	0.5	70	8.02	0.8	599	2.09	0.29	0.46	1.32	68.9	6.46	97	17.7	25	20.9	1.5	3.96	37.4	19.5	54.2	1.58	1175
37-38	0.5	50	8.04	0.7	621	1.80	0.30	0.46	1.31	68.6	6.56	99	18.6	24	20.8	1.5	3.98	37.4	19.5	53.4	1.59	1195
38-39	3	50	7.99	0.8	594	2.41	0.30	0.50	1.29	69.6	6.71	94	19.7	24	22.0	1.6	4.00	38.9	19.0	56.4	1.52	1155
39-40	1	50	8.08	0.7	566	2.22	0.32	0.51	1.30	67.5	6.66	91	18.5	26	21.2	1.5	3.88	37.9	19.5	56.2	1.55	1180
40-41	2	50	7.92	0.8	569	2.38	0.32	0.55	1.32	71.0	6.56	91	19.0	26	21.4	1.5	3.89	39.9	20.5	54.3	1.52	1170
41-42	3	50	7.98	0.8	651	1.98	0.32	0.55	1.29	70.1	6.66	92	19.6	26	21.5	1.5	3.85	39.4	20.5	54.5	1.50	1160
42-43	2	50	8.17	0.8	624	2.09	0.31	0.54	1.34	70.2	6.61	94	18.1	27	20.9	1.5	3.93	39.4	21.0	54.1	1.60	1230
43-44	1	50	8.15	0.8	596	1.80	0.34	0.52	1.38	69.0	6.71	93	18.0	26	21.0	1.5	3.90	39.4	20.0	54.5	1.61	1240
44-45	3	50	8.02	0.8	588	2.31	0.33	0.54	1.38	68.9	6.81	90	17.2	25	21.0	1.5	3.86	39.4	20.0	53.8	1.57	1200
45-46	3	50	8.42	0.8	611	2.12	0.33	0.53	1.48	66.5	6.86	93	18.3	25	21.3	1.7	4.04	38.4	19.0	53.2	1.69	1315
46-47	2	40	7.73	10.3	555	2.18	0.41	0.52	1.42	66.1	6.74	87	18.6	22	21.4	1.6	3.70	37.6	20.5	54.0	1.52	1215
47-48	3	50	8.32	1.0	577	2.14	0.28	0.50	1.49	64.6	6.64	94	17.2	24	21.1	1.6	3.97	36.6	18.5	55.0	1.63	1290
48-49	2	60	8.40	1.0	579	2.40	0.32	0.54	1.53	68.0	6.74	96	18.9	25	22.0	1.7	4.00	38.6	19.5	55.8	1.67	1345
49-50	3	50	8.50	0.9	592	2.11	0.32	0.57	1.56	67.3	6.59	97	17.5	25	21.3	1.6	3.90	37.6	20.5	53.6	1.67	1310
50-51	4	50	7.87	1.0	604	2.12	0.33	0.57	1.41	68.9	7.57	89	16.8	25	20.7	1.6	3.70	39.3	21.0	54.8	1.60	1205
51-52	3	50	7.77	1.0	567	1.68	0.32	0.57	1.31	65.6	6.32	92	17.1	26	20.7	1.6	3.65	36.8	20.5	52.2	1.47	1185
52-53	1	50	8.18	0.8	609	1.99	0.28	0.54	1.29	66.4	6.56	96	18.7	26	20.8	1.6	4.09	36.4	19.0	54.2	1.56	1230
53-54	0.5	50	7.93	0.8	582	2.25	0.33	0.60	1.23	67.8	6.51	98	18.4	27	20.8	1.6	3.99	37.4	19.0	55.3	1.52	1235
54-55	3	50	8.12	0.8	564	2.16	0.31	0.56	1.26	69.1	6.71	94	19.6	26	21.1	1.6	4.04	38.4	19.5	56.7	1.53	1260
55-56	1	50	8.31	0.8	597	2.37	0.32	0.55	1.24	69.2	6.71	100	18.7	28	21.8	1.6	4.10	38.4	19.5	55.9	1.58	1320
56-57	3	40	8.05	0.9	569	2.57	0.34	0.53	1.21	71.9	7.01	94	19.4	26	22.7	1.7	3.94	40.9	20.5	58.9	1.52	1225
57-58	1	50	8.16	0.8	592	2.08	0.33	0.55	1.19	70.0	6.86	95	19.6	27	22.1	1.6	3.89	39.4	19.0	57.7	1.47	1215
58-59	2	50	8.36	0.8	614	2.14	0.33	0.50	1.16	70.0	7.01	97	17.7	27	22.0	1.5	4.03	39.9	20.0	57.0	1.53	1265
59-60	1	40	8.54	0.8	617	2.15	0.33	0.52	1.19	70.8	7.11	97	18.5	27	22.3	1.6	4.14	40.4	21.5	58.0	1.54	1280
60-61	3	50	8.43	0.8	569	2.51	0.35	0.52	1.18	71.2	7.11	96	18.8	26	21.8	1.6	4.12	40.4	20.5	55.8	1.50	1255
61-62	2	50	8.37	0.8	572	1.97	0.33	0.49	1.22	68.1	6.86	92	18.9	27	21.5	1.8	3.83	39.4	19.5	55.0	1.49	1240
62-63	2	50	8.24	1.0	575	2.08	0.35	0.56	1.20	70.8	7.29	97	19.8	12	22.2	1.6	4.00	40.6	22.0	59.3	1.52	1270
63-64	3	50	8.23	0.9	578	2.14	0.31	0.46	1.17	66.7	6.69	94	18.8	25	21.3	1.6	3.96	37.6	20.0	54.4	1.47	1310

Table 15 continued

Depth cm	As ppm	Hg ppb	Al %	Sb ppm	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ca %	Ce ppm	Cs ppm	Cr ppm	Co ppm	Cu ppm	Ga ppm	Ge ppm	Fe %	La ppm	Pb ppm	Li ppm	Mg %	Mn ppm
64-65	3	40	8.38	1.0	570	2.10	0.31	0.46	1.15	67.2	6.79	94	18.9	31	21.8	1.6	4.07	37.6	20.0	56.2	1.50	1305
65-66	3	40	8.72	0.9	613	2.36	0.34	0.53	1.20	69.0	6.99	102	18.5	27	22.3	1.6	4.11	39.1	21.0	56.6	1.53	1350
66-67	4	50	8.15	0.9	605	1.82	0.32	0.51	1.09	65.9	6.07	95	17.8	27	21.1	1.7	3.93	37.3	20.0	54.0	1.41	1240
67-68	4	40	7.84	0.9	598	2.23	0.31	0.53	1.08	65.7	6.77	92	16.3	26	20.9	1.6	3.78	37.3	21.0	53.8	1.41	1210
68-69	0.5	60	8.00	0.8	630	2.29	0.29	0.56	1.20	68.5	6.36	95	18.7	25	20.4	1.5	3.94	37.4	19.0	52.5	1.47	1180
69-70	1	60	7.98	0.8	623	1.75	0.32	0.48	1.31	69.1	6.46	97	18.2	26	20.5	1.6	4.01	37.9	20.0	51.9	1.58	1215
70-71	3	50	7.96	0.9	605	2.06	0.30	0.54	1.28	69.9	6.66	92	19.6	25	21.4	1.6	3.92	37.9	19.5	56.9	1.52	1215
71-72	4	50	8.13	0.8	588	2.01	0.30	0.53	1.28	70.6	6.61	96	18.7	27	21.5	1.6	3.96	39.4	20.0	55.8	1.54	1195
72-73	4	50	7.96	0.8	590	2.12	0.32	0.51	1.26	70.5	6.71	91	17.8	25	21.7	1.6	3.86	39.4	20.0	56.2	1.48	1205
73-74	2	60	7.93	0.8	583	1.88	0.31	0.51	1.31	68.3	6.36	93	18.0	27	21.0	1.5	3.83	38.9	19.0	54.6	1.54	1230
74-75	3	50	8.14	0.9	605	2.29	0.34	0.56	1.31	72.7	6.96	95	19.3	27	21.7	1.6	4.01	41.4	21.0	56.8	1.57	1270
75-76	3	60	8.23	0.8	618	2.00	0.34	0.52	1.31	71.2	6.81	94	19.7	28	21.4	1.5	4.01	40.4	20.5	56.0	1.59	1375
76-77	5	50	8.23	0.8	590	1.96	0.33	0.54	1.26	68.2	6.81	91	19.8	26	21.0	1.5	3.97	38.9	20.0	53.3	1.53	1275
77-78	3	50	8.43	0.8	602	2.12	0.33	0.53	1.27	68.8	6.86	90	17.5	26	21.5	1.5	4.12	39.4	20.0	52.7	1.55	1275
78-79	3	50	8.14	1.1	576	1.98	0.32	0.52	1.22	68.1	6.49	91	17.8	25	20.5	1.6	3.91	38.6	21.5	53.4	1.48	1210
79-80	3	50	8.30	0.9	609	2.14	0.30	0.54	1.23	69.2	6.64	96	19.2	26	21.7	1.7	3.98	38.6	19.5	52.0	1.52	1245
80-81	1	60	8.33	0.9	591	2.20	0.35	0.52	1.28	68.8	6.44	93	19.1	31	21.5	1.7	4.00	38.1	20.5	55.2	1.57	1285
81-82	3	40	8.31	1.1	583	2.16	0.32	0.49	1.27	68.9	6.94	97	18.1	29	21.7	1.6	3.89	39.1	20.5	56.4	1.55	1265
82-83	3	40	8.07	1.0	646	2.22	0.32	0.51	1.30	67.7	6.52	95	17.4	27	21.3	1.7	3.95	38.3	20.5	55.8	1.57	1305
83-84	5	50	7.72	1.0	578	1.98	0.33	0.47	1.20	65.3	5.97	93	17.7	27	21.2	1.6	3.87	36.8	21.0	53.2	1.44	1280
84-85	1	50	8.19	0.9	631	1.99	0.31	0.50	1.27	69.6	6.81	103	18.1	26	21.2	1.5	4.00	37.9	19.5	55.1	1.59	1340
85-86	0.5	60	8.09	0.8	643	1.80	0.31	0.48	1.22	68.7	6.76	98	18.8	25	21.6	1.6	3.99	38.4	19.5	55.6	1.56	1280
86-87	3	60	8.18	0.8	606	1.95	0.29	0.54	1.21	65.6	6.66	94	19.2	25	21.2	1.6	4.04	35.9	18.5	55.4	1.49	1225
87-88	3	50	8.29	0.9	598	2.21	0.33	0.53	1.27	71.6	7.01	96	18.9	26	22.6	1.7	4.05	40.4	20.5	58.4	1.55	1280
88-89	5	50	8.02	0.8	581	2.42	0.30	0.47	1.25	67.9	6.66	92	19.4	25	21.4	1.6	3.85	38.4	18.0	56.6	1.53	1250
89-90	2	60	8.12	0.8	573	2.03	0.31	0.49	1.23	70.4	6.66	93	20.4	25	21.3	1.6	3.83	39.4	19.5	55.5	1.50	1225
90-91	3	50	7.92	0.8	586	2.29	0.33	0.55	1.37	70.9	6.71	91	18.9	26	21.4	1.6	3.82	39.9	20.5	53.5	1.56	1240
91-92	1	40	8.17	0.8	568	1.85	0.31	0.50	1.33	67.1	6.56	90	17.3	25	20.6	1.5	3.83	37.9	19.5	54.5	1.55	1285
92-93	1	50	8.39	0.9	591	2.06	0.33	0.48	1.36	68.9	6.91	94	18.2	25	21.5	1.5	4.13	39.9	20.5	55.7	1.59	1305
93-94	3	50	8.20	0.9	583	2.12	0.33	0.48	1.36	66.6	6.76	93	17.5	26	20.9	1.5	3.97	38.4	19.0	51.8	1.61	1305
94-95	3	50	8.02	1.7	577	2.18	0.27	0.50	1.32	67.7	6.74	97	18.3	25	21.3	1.7	3.91	38.1	20.0	54.2	1.56	1270
95-96	2	40	7.83	1.7	549	2.14	0.30	0.48	1.26	66.3	6.64	89	18.4	24	20.8	1.6	3.86	37.6	19.5	52.8	1.51	1210

Table 15 continued

Depth cm	As ppm	Hg ppb	Al %	Sb ppm	Ba ppm	Be ppm	Bi ppm	Cd ppm	Ca %	Ce ppm	Cs ppm	Cr ppm	Co ppm	Cu ppm	Ga ppm	Ge ppm	Fe %	La ppm	Pb ppm	Li ppm	Mg %	Mn ppm
96-97	3	50	7.58	0.8	552	1.85	0.33	0.50	1.30	65.5	6.49	84	17.7	26	20.7	1.5	3.73	36.6	19.0	52.4	1.48	1190
97-98	5	70	8.27	0.9	584	2.41	0.31	0.57	1.52	70.2	6.64	98	18.5	27	21.3	1.5	4.17	39.1	20.5	55.4	1.68	1370
98-99	3	40	7.72	1.0	627	1.87	0.30	0.51	1.74	63.1	6.62	101	16.6	26	19.3	1.5	3.68	35.8	19.5	52.2	1.69	1410
99-100	6	50	7.87	1.2	619	1.93	0.34	0.61	1.50	71.0	6.97	91	19.2	28	20.8	1.7	3.67	40.3	22.5	53.4	1.59	1455
100-101	3	50	7.89	0.9	612	1.99	0.27	0.49	1.31	66.9	6.46	93	17.5	24	20.0	1.5	3.81	36.4	18.5	52.2	1.54	1260
101-102	3	50	8.05	0.8	634	2.05	0.31	0.54	1.33	68.9	6.56	116	18.6	27	20.9	1.5	3.96	37.9	19.0	54.2	1.58	1335
102-103	2	60	7.97	0.9	597	2.00	0.31	0.52	1.25	69.4	6.71	92	18.4	25	22.0	1.6	4.00	38.4	19.5	54.7	1.51	1260
103-104	4	50	8.07	0.8	589	1.96	0.32	0.58	1.26	69.1	6.51	93	18.3	26	21.4	1.6	4.01	37.9	20.5	54.3	1.52	1270
104-105	6	60	8.20	0.8	612	2.07	0.31	0.55	1.31	69.7	6.76	96	19.9	28	21.9	1.6	4.00	39.4	19.5	56.3	1.56	1305
105-106	3	50	8.00	0.8	574	2.33	0.32	0.55	1.30	70.2	6.76	93	20.0	26	21.8	1.6	3.89	39.4	20.5	56.5	1.56	1380
106-107	4	50	8.06	0.8	577	2.09	0.31	0.53	1.34	66.5	6.56	92	17.7	26	20.5	1.5	3.95	37.4	19.5	53.7	1.58	1345
107-108	4	50	8.06	0.8	579	2.10	0.31	0.54	1.45	66.4	6.61	90	18.1	25	20.8	1.5	3.82	37.4	19.5	54.0	1.61	1375
108-109	3	50	8.12	1.0	591	2.11	0.32	0.56	1.41	68.2	6.76	92	19.2	25	20.9	1.6	3.95	38.4	20.0	52.6	1.61	1415
109-110	4	50	8.50	0.9	634	2.07	0.35	0.56	1.33	68.1	6.91	95	18.8	28	21.6	1.5	4.16	38.9	20.5	53.6	1.62	1465
110-111	3	40	7.96	1.0	588	1.83	0.28	0.55	1.26	66.2	6.29	90	17.1	24	20.5	1.5	3.91	36.6	20.0	52.0	1.50	1270
111-112	2	30	8.51	0.9	600	1.99	0.30	0.50	1.24	67.9	6.54	96	17.2	26	21.1	1.6	4.21	38.1	20.0	52.0	1.57	1470
112-113	4	50	8.26	1.0	602	1.95	0.30	0.54	1.30	69.1	6.54	93	19.9	25	21.0	1.6	3.92	38.6	20.0	53.2	1.55	1765
113-114	6	50	8.43	0.9	585	2.36	0.34	0.62	1.31	70.8	6.54	95	20.5	26	21.4	1.6	4.00	39.1	22.0	54.8	1.57	2210
114-115	4	50	7.93	0.9	617	2.02	0.33	0.57	1.21	71.8	7.27	92	18.8	27	21.1	1.7	3.73	40.3	21.5	55.6	1.50	1620
115-116	6	40	8.11	0.9	630	1.93	0.32	0.51	1.14	68.8	7.02	96	17.6	29	20.9	1.6	3.95	39.3	20.5	55.4	1.47	1250
116-117	3	50	8.04	0.8	602	1.84	0.28	0.47	1.15	68.6	6.36	93	16.7	25	20.4	1.5	3.82	37.4	19.0	51.3	1.46	1175
117-118	3	50	8.18	0.9	585	2.34	0.32	0.54	1.34	70.4	6.81	127	17.6	26	21.9	1.6	3.73	38.4	19.5	56.3	1.52	1170
118-119	2	50	8.14	0.8	607	2.20	0.28	0.52	1.43	65.1	6.51	94	17.4	25	20.8	1.5	3.83	36.4	17.5	53.5	1.64	1310
119-120	3	50	7.98	0.7	570	1.86	0.22	0.36	1.52	49.5	5.11	91	14.7	24	16.6	1.2	3.61	27.9	14.5	42.9	1.61	1140
120-121	4	40	8.08	0.9	562	2.42	0.30	0.51	1.56	67.6	6.86	91	19.9	23	22.4	1.6	3.83	38.4	19.5	58.2	1.66	1205
121-122	3	40	7.99	0.9	605	2.18	0.31	0.47	1.55	64.8	6.66	92	17.6	24	20.7	1.4	3.75	36.9	19.0	53.8	1.71	1250
122-123	3	40	8.13	0.9	597	1.89	0.31	0.53	1.55	66.8	6.81	91	18.1	24	21.8	1.6	3.86	37.9	19.0	56.0	1.71	1255
123-124	3	50	8.16	0.9	570	2.15	0.32	0.52	1.57	68.5	6.96	93	18.1	25	21.6	1.5	3.82	38.9	20.0	55.6	1.71	1295
124-125	0.5	50	6.66	0.7	462	1.56	0.25	0.42	1.27	53.9	5.51	74	14.0	20	17.3	1.3	3.06	30.9	16.0	44.8	1.36	1025
125-126	5	50	8.37	0.9	625	1.77	0.34	0.54	1.59	65.1	6.86	92	17.4	25	21.0	1.5	3.96	37.9	19.0	52.1	1.75	1305
126-127	2	40	7.89	13.9	598	1.88	0.86	0.51	1.53	63.7	6.54	91	17.9	23	20.9	1.6	3.76	35.6	20.0	53.4	1.65	1200
127-128	3	40	8.01	1.0	571	1.84	0.29	0.46	1.49	64.7	6.34	92	16.8	24	20.7	1.5	3.81	36.6	18.5	51.6	1.65	1225

Table 15 continued

Depth	As	Hg	Al	Sb	Ba	Be	Bi	Cd	Ca	Ce	Cs	Cr	Co	Cu	Ga	Ge	Fe	La	Pb	Li	Mg	Mn
cm	ppm	ppb	%	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	%	ppm
128-129	3	50	8.62	0.9	613	2.05	0.29	0.48	1.53	67.5	6.69	95	18.5	25	21.6	1.6	4.00	38.1	19.5	53.8	1.73	1265
129-130	3	40	8.33	4.4	586	2.21	0.34	0.50	1.46	67.7	6.84	93	18.1	26	22.0	1.7	3.82	38.1	19.5	56.8	1.65	1200
130-131	2	40	7.92	1.0	588	2.12	0.31	0.49	1.41	64.9	6.27	122	16.6	24	19.8	1.6	3.51	36.8	18.5	55.0	1.57	1100
131-132	3	40	8.15	1.0	591	1.98	0.32	0.51	1.54	66.4	7.42	94	16.4	27	20.4	1.6	3.60	37.8	20.0	54.8	1.67	1180
132-133	2	50	8.10	0.9	623	2.08	0.29	0.47	1.53	67.4	6.66	93	17.9	25	20.7	1.6	3.80	36.4	20.0	52.5	1.69	1225
133-134	1	50	7.97	0.8	616	1.69	0.29	0.48	1.49	65.2	6.26	118	18.8	26	20.2	1.5	3.74	35.4	17.5	53.5	1.69	1185
134-135	3	50	7.98	0.8	608	2.30	0.29	0.54	1.57	67.0	6.36	94	19.8	26	20.8	1.5	3.71	36.4	18.5	53.0	1.68	1155
135-136	2	50	8.06	0.9	591	2.31	0.30	0.46	1.42	65.6	6.66	93	19.9	26	21.8	1.6	3.85	36.4	19.5	55.0	1.63	1210
136-137	4	40	8.33	0.9	583	2.02	0.30	0.43	1.41	67.0	7.06	96	18.7	25	22.4	1.7	4.01	37.9	18.5	58.0	1.69	1255
137-138	4	50	8.39	0.9	566	2.03	0.32	0.47	1.50	66.8	7.26	96	18.2	25	22.6	1.8	3.98	37.9	18.5	58.4	1.69	1265
138-139	2	40	8.15	0.9	588	2.19	0.31	0.41	1.41	67.5	6.91	93	18.9	26	22.3	1.6	3.85	38.9	19.0	57.1	1.62	1190
139-140	2	50	8.31	0.9	621	1.80	0.32	0.54	1.44	70.1	6.96	93	18.5	27	22.2	1.6	3.97	40.4	20.0	57.5	1.67	1205
140-141	0.5	40	4.88	0.5	353	1.11	0.18	0.32	0.89	38.5	3.76	54	10.0	16	12.5	0.9	2.26	21.9	11.0	32.5	0.97	715
141-142	3	40	8.39	0.9	615	2.22	0.33	0.56	1.51	68.1	6.86	93	18.6	27	21.0	1.6	3.94	39.4	19.5	52.1	1.73	1200
142-143	3	30	7.91	0.9	619	2.03	0.26	0.49	1.44	68.5	6.44	94	19.5	26	20.5	1.6	3.86	38.6	20.0	52.0	1.63	1105
143-144	0.5	40	8.10	3.2	592	2.29	0.32	0.46	1.33	68.9	6.34	90	22.6	25	20.6	1.5	3.88	38.6	20.0	53.4	1.58	1055
144-145	3	40	8.31	0.9	614	2.45	0.29	0.50	1.48	69.4	6.54	96	20.8	26	21.6	1.6	4.07	39.1	19.5	54.4	1.67	1235
145-146	5	40	8.14	0.9	596	1.81	0.49	0.44	1.36	67.2	6.34	91	17.1	27	21.4	1.6	3.93	37.6	19.5	54.6	1.56	1285
146-147	4	50	7.79	0.9	589	2.17	0.30	0.51	1.28	66.1	5.77	95	16.0	27	20.8	1.6	3.68	37.3	20.0	55.6	1.48	1105
14-148	4	50	7.87	1.0	601	1.82	0.32	0.49	1.32	68.6	6.77	91	17.0	29	21.2	1.7	3.74	38.8	21.0	55.8	1.55	1110
148-149	3	50	8.17	0.8	644	1.83	0.28	0.45	1.38	68.7	6.51	96	18.7	28	21.0	1.5	3.93	37.4	18.5	53.2	1.67	1190
149-150	0.5	60	7.76	0.7	596	1.49	0.22	0.40	1.60	52.5	4.81	86	13.7	25	15.5	1.1	3.57	28.4	14.0	39.4	1.71	1190
150-151	4	50	8.00	0.9	629	1.95	0.29	0.48	1.76	69.1	6.51	95	18.4	25	21.2	1.5	3.82	37.9	18.5	54.2	1.80	1245
151-152	3	60	7.85	0.8	591	1.91	0.27	0.42	1.69	63.2	6.11	92	18.1	25	20.3	1.5	3.79	34.9	17.5	53.0	1.73	1240
152-153	2	50	8.07	0.9	584	2.67	0.30	0.53	1.51	71.0	6.91	93	19.1	26	22.5	1.7	3.98	39.9	20.0	57.9	1.64	1200
153-154	3	50	8.14	0.8	606	2.13	0.31	0.45	1.48	65.9	6.46	93	18.4	25	21.0	1.5	3.96	37.4	19.0	55.1	1.69	1160
154-155	2	50	8.00	0.8	579	2.14	0.30	0.47	1.47	67.8	6.66	92	19.6	26	21.8	1.6	3.96	37.9	19.0	55.9	1.65	1105
155-156	2	40	8.24	0.9	601	2.30	0.33	0.48	1.51	71.5	6.81	94	19.5	27	21.8	1.6	4.01	40.4	20.5	56.9	1.68	1035
156-157	0.5	50	8.25	0.8	624	1.96	0.31	0.50	1.43	72.0	6.61	93	19.0	27	21.3	1.5	4.09	40.4	20.0	52.6	1.63	1175
157-158	4	40	8.44	0.8	646	2.36	0.34	0.52	1.41	71.8	6.86	94	19.2	28	21.7	1.6	4.08	40.9	20.0	53.8	1.69	1255
Mean	3	56	8.12	1.1	589	2.09	0.32	0.51	1.33	67.6	6.66	95	18.3	26	21.2	1.58	3.92	38.1	20.63	54.6	1.57	1213
St.Dev.	1.49	19.83	0.36	1.32	33.87	0.21	0.05	0.05	0.14	3.89	0.42	7.50	1.35	2.13	1.18	0.10	0.21	2.25	2.74	3.10	0.09	151

Table 15 continued

Depth	Mo	Ni	Nb	P	K	Rb	Ag	Na	Sr	Ta	Te	Tl	Th	Ti	W	U	V	Y	Zn
cm	ppm	ppm	ppm	ppm	%	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm
0-1	1.0	43.7	13.1	810	1.93	108.4	1.25	0.57	119.9	0.95	0.10	0.70	12.9	0.34	2.6	2.9	194	18.1	126
1-2	1.8	45.5	13.9	850	2.03	115.9	0.80	0.58	121.3	0.95	0.10	0.72	13.7	0.35	1.4	3.1	191	18.7	124
2-3	0.8	45.9	13.3	850	1.92	113.4	0.70	0.57	123.2	0.95	0.05	0.68	13.4	0.35	1.3	2.9	195	18.7	125
3-4	0.8	43.3	13.3	950	1.90	121.8	0.60	0.53	121.5	0.90	0.10	0.68	13.2	0.34	1.2	2.9	186	19.3	132
4-5	0.8	43.0	13.1	800	1.84	110.4	0.60	0.50	107.4	1.00	0.10	0.74	13.1	0.34	1.3	3.1	183	18.2	118
5-6	0.8	44.2	13.3	870	1.92	114.5	0.85	0.55	119.3	1.00	0.10	0.72	13.9	0.35	1.3	2.9	199	18.7	131
6-7	0.8	44.0	13.3	860	1.91	116.0	0.65	0.55	122.6	0.95	0.05	0.68	13.2	0.34	1.3	2.9	196	18.7	129
7-8	1.0	50.7	14.1	850	1.93	119.5	0.65	0.57	121.5	1.00	0.15	0.72	13.8	0.34	1.4	3.1	199	19.4	126
8-9	0.8	44.0	12.5	790	1.89	111.0	0.75	0.55	113.9	0.85	0.05	0.64	12.5	0.33	1.2	2.7	188	17.8	131
9-10	0.8	46.8	13.7	850	1.93	118.5	0.65	0.54	121.8	1.00	0.10	0.70	13.5	0.34	1.3	3.1	194	19.4	131
10-11	0.8	48.1	14.3	840	1.98	121.5	0.70	0.58	124.6	1.00	0.10	0.72	14.0	0.35	1.4	3.1	203	19.8	132
11-12	0.8	45.5	13.1	780	1.93	114.5	0.65	0.56	120.0	0.85	0.10	0.66	12.8	0.35	1.2	2.9	193	18.6	128
12-13	0.8	45.1	12.5	840	2.02	116.0	0.70	0.60	124.9	0.90	0.10	0.70	13.9	0.34	1.2	3.1	210	18.5	135
13-14	0.8	45.1	13.7	810	2.01	115.5	0.70	0.59	125.2	0.95	0.05	0.72	14.1	0.36	1.3	3.1	201	19.3	130
14-15	0.8	45.3	12.5	780	1.93	113.5	0.70	0.55	122.6	0.90	0.15	0.70	13.8	0.36	1.3	2.9	193	18.8	122
15-16	1.2	45.9	13.1	780	1.81	111.4	0.65	0.56	125.9	0.95	0.10	0.72	13.8	0.34	1.6	3.1	196	19.2	126
16-17	1.2	47.7	13.5	760	1.86	114.4	0.70	0.61	127.3	0.95	0.15	0.74	14.5	0.35	1.3	3.1	192	19.4	124
17-18	1.0	46.5	13.1	730	1.91	111.9	0.70	0.60	124.6	0.85	0.05	0.68	13.5	0.35	1.7	2.9	189	18.9	123
18-19	1.2	46.9	13.7	740	1.98	123.9	0.65	0.58	133.0	1.00	0.10	0.74	15.0	0.35	1.3	3.3	188	19.6	126
19-20	1.0	43.7	13.5	740	1.98	117.8	0.70	0.86	117.9	1.00	0.15	0.76	14.2	0.29	1.4	3.1	171	19.6	112
20-21	1.0	45.6	13.9	710	1.95	116.5	0.55	0.61	125.7	1.00	0.20	0.74	14.5	0.36	1.4	3.1	190	19.9	121
21-22	0.8	45.2	13.3	670	1.89	114.0	0.50	0.58	124.1	0.90	0.15	0.68	13.3	0.34	1.3	2.9	193	19.0	117
22-23	1.2	55.1	14.3	720	1.96	122.5	0.65	0.61	125.0	1.00	0.10	0.74	14.4	0.36	1.4	3.1	190	20.5	124
23-24	0.8	46.6	13.7	670	1.92	116.5	0.50	0.59	123.4	0.95	0.10	0.68	13.4	0.35	1.4	2.9	189	19.2	117
24-25	0.8	43.8	13.1	670	1.99	112.5	0.50	0.63	124.7	0.90	0.05	0.68	13.3	0.36	1.3	2.7	196	18.8	121
25-26	0.8	46.4	13.9	660	1.99	116.0	0.50	0.61	124.1	0.95	0.10	0.70	13.3	0.35	1.2	2.9	188	19.4	120
26-27	0.8	47.9	14.1	680	1.99	119.5	0.60	0.61	128.0	0.95	0.10	0.66	13.6	0.36	1.3	2.7	191	19.8	118
27-28	0.8	47.9	13.9	640	1.99	120.5	0.50	0.60	125.3	0.95	0.10	0.74	14.4	0.37	1.3	2.9	183	20.2	111
28-29	0.8	45.9	13.1	650	1.99	116.5	0.55	0.61	126.7	0.95	0.05	0.72	14.3	0.36	1.3	2.9	194	19.2	114
29-30	0.6	44.9	11.7	650	1.98	115.0	0.45	0.56	124.1	0.85	0.10	0.72	13.7	0.34	1.2	2.7	194	18.4	114
30-31	1.6	42.4	13.5	680	2.03	113.4	0.50	0.57	124.4	0.95	0.10	0.68	13.4	0.35	3.4	2.7	187	19.0	116
31-32	0.8	46.5	13.5	680	2.05	118.4	0.55	0.57	126.2	0.95	0.10	0.74	13.9	0.35	1.4	2.7	192	19.4	114

Table 15 continued

Depth	Mo	Ni	Nb	P	K	Rb	Ag	Na	Sr	Ta	Te	Tl	Th	Ti	W	U	V	Y	Zn
cm	ppm	ppm	ppm	ppm	%	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm
32-33	1.0	46.1	13.3	670	1.97	112.4	0.60	0.57	126.6	0.85	0.10	0.68	12.9	0.35	1.5	2.7	192	19.1	111
33-34	0.8	45.1	13.7	680	2.04	115.4	0.60	0.61	127.5	0.95	0.15	0.72	13.8	0.36	1.8	2.7	185	19.2	109
34-35	1.0	42.9	13.3	760	1.99	121.8	0.45	0.65	127.8	1.00	0.10	0.72	14.0	0.34	1.3	2.9	186	19.8	112
35-36	1.2	51.4	13.1	680	1.91	94.6	0.50	0.58	111.2	0.95	0.05	0.66	12.1	0.35	1.4	2.7	190	17.3	117
36-37	0.8	43.5	12.7	670	1.90	111.5	0.50	0.59	124.1	0.90	0.05	0.68	13.3	0.34	1.2	2.7	189	18.8	115
37-38	0.8	45.4	13.1	660	1.91	110.0	0.45	0.59	124.4	0.90	0.10	0.68	13.2	0.34	1.2	2.7	192	18.8	116
38-39	0.8	47.0	13.7	680	1.92	116.5	0.50	0.59	126.3	0.90	0.10	0.66	13.2	0.34	1.2	2.7	190	19.4	115
39-40	0.8	46.2	12.9	640	1.95	114.5	0.50	0.60	126.2	0.85	0.10	0.68	13.3	0.35	1.2	2.7	189	19.3	113
40-41	0.8	47.0	14.3	650	1.93	112.5	0.55	0.62	126.6	0.95	0.05	0.70	13.5	0.36	1.3	2.7	188	20.0	116
41-42	0.8	47.2	13.9	640	1.95	113.5	0.60	0.62	126.4	0.95	0.10	0.70	13.6	0.35	1.3	2.9	185	19.8	112
42-43	0.8	44.7	13.7	660	1.98	111.0	0.55	0.64	130.3	1.05	0.05	0.70	13.6	0.37	1.3	2.9	195	19.3	115
43-44	0.8	44.9	13.9	650	1.97	111.5	0.50	0.62	128.2	1.00	0.15	0.72	13.9	0.37	1.3	2.9	195	19.3	114
44-45	0.8	43.9	13.5	610	1.93	112.0	0.50	0.59	123.5	1.00	0.05	0.70	13.7	0.35	1.4	2.7	189	19.1	110
45-46	0.8	46.3	13.1	690	1.99	113.0	0.50	0.59	127.4	0.90	0.05	0.72	13.4	0.36	1.3	2.7	200	19.5	111
46-47	7.6	45.6	13.5	640	1.80	108.4	1.45	0.55	123.3	0.95	0.15	0.68	13.2	0.34	4.2	2.7	188	19.1	108
47-48	1.6	43.0	13.5	680	2.02	111.4	0.50	0.56	125.2	0.90	0.10	0.68	12.7	0.35	1.4	2.5	201	18.8	114
48-49	1.0	46.5	13.9	690	1.88	110.4	0.55	0.58	130.6	0.95	0.15	0.68	13.3	0.35	1.7	2.7	199	19.7	115
49-50	0.8	44.1	13.5	710	2.11	111.9	1.10	0.63	128.4	1.00	0.15	0.74	13.8	0.37	1.6	2.7	199	19.1	113
50-51	1.0	42.1	13.5	1060	1.92	125.3	0.45	0.78	123.3	1.00	0.10	0.74	13.8	0.32	1.3	2.9	186	20.3	112
51-52	1.0	42.7	13.5	650	1.90	106.0	0.45	0.56	117.2	0.95	0.10	0.70	12.7	0.36	1.4	2.9	184	18.6	113
52-53	1.0	46.3	12.9	660	1.91	110.5	0.45	0.58	123.5	0.90	0.05	0.68	13.1	0.35	1.3	2.7	198	19.1	119
53-54	1.0	45.1	13.1	670	1.87	110.0	0.45	0.56	121.9	0.90	0.10	0.72	13.0	0.34	1.2	2.7	199	18.9	120
54-55	1.0	48.4	13.7	640	1.92	113.5	0.50	0.58	125.8	0.90	0.10	0.68	13.2	0.35	1.4	2.7	202	19.8	116
55-56	1.0	46.6	14.1	680	1.98	116.0	0.50	0.59	127.6	0.95	0.10	0.70	13.7	0.36	1.3	2.7	209	19.7	127
56-57	0.8	48.4	14.9	640	1.94	118.5	0.55	0.59	124.5	1.00	0.15	0.76	14.1	0.36	1.4	2.9	197	20.3	118
57-58	0.8	47.6	14.1	660	1.96	116.0	0.50	0.60	123.9	0.95	0.10	0.68	13.6	0.36	1.3	2.7	193	19.8	114
58-59	0.8	45.4	14.1	660	1.99	117.0	0.50	0.60	127.8	1.00	0.10	0.74	14.2	0.37	1.4	2.9	203	19.6	117
59-60	0.8	46.3	14.1	660	2.04	118.0	0.55	0.62	126.6	1.00	0.05	0.74	14.5	0.37	1.4	2.9	203	19.8	120
60-61	0.8	46.3	13.9	650	2.00	116.0	0.50	0.62	126.5	1.05	0.10	0.72	14.7	0.38	1.4	2.9	198	19.6	114
61-62	0.8	46.5	13.5	640	1.97	114.0	0.55	0.60	122.9	0.95	0.10	0.66	13.6	0.37	1.3	2.7	188	19.5	111
62-63	1.3	53.4	14.7	680	1.87	117.4	0.65	0.58	117.3	1.05	0.20	0.72	15.8	0.36	3	2.9	198	20.5	113
63-64	0.8	45.4	13.1	660	1.89	111.4	0.50	0.56	122.2	0.90	0.10	0.68	13.7	0.35	1.3	2.7	194	18.6	114

Table 15 continued

Depth cm	Mo ppm	Ni ppm	Nb ppm	P ppm	K %	Rb ppm	Ag ppm	Na %	Sr ppm	Ta ppm	Te ppm	Tl ppm	Th ppm	Ti %	W ppm	U ppm	V ppm	Y ppm	Zn ppm
64-65	0.8	47.4	13.5	670	2.01	114.4	0.55	0.56	123.5	0.90	0.10	0.70	13.5	0.36	2.1	2.7	199	19.1	115
65-66	0.8	48.1	13.5	720	2.15	121.4	0.55	0.55	128.4	0.95	0.10	0.74	14.4	0.36	1.4	2.7	205	19.7	117
66-67	0.8	43.9	13.5	700	1.98	103.8	0.50	0.58	122.3	1.00	0.10	0.72	13.0	0.37	1.3	2.7	192	18.9	118
67-68	0.8	41.3	13.7	650	1.92	111.6	0.45	0.58	118.6	1.00	0.05	0.72	13.1	0.36	1.3	2.7	186	18.8	111
68-69	0.8	45.5	13.1	660	1.90	109.5	0.45	0.60	123.5	0.90	0.10	0.68	13.1	0.35	1.3	2.7	187	18.8	113
69-70	0.8	45.9	12.9	680	1.93	109.5	0.45	0.62	130.4	0.90	0.10	0.66	13.0	0.34	1.2	2.7	195	19.1	118
70-71	0.8	47.1	13.7	670	1.91	113.5	0.50	0.61	126.7	0.95	0.15	0.66	13.2	0.34	1.2	2.7	189	19.5	114
71-72	0.8	47.4	13.9	680	1.97	114.0	0.55	0.63	128.6	0.95	0.10	0.68	13.5	0.35	1.3	2.7	191	19.8	119
72-73	0.8	45.2	14.1	630	1.94	116.0	0.50	0.63	127.5	1.00	0.05	0.70	13.7	0.35	1.3	2.7	187	20.0	114
73-74	0.8	46.6	13.9	650	1.93	112.5	0.50	0.63	129.8	0.90	0.10	0.68	13.0	0.35	1.2	2.7	192	19.6	120
74-75	1.0	47.8	14.7	660	1.97	118.0	0.55	0.61	130.2	1.00	0.05	0.74	14.4	0.37	1.4	2.9	194	20.3	115
75-76	1.0	46.4	13.9	650	1.98	112.5	0.50	0.63	129.1	1.00	0.15	0.70	14.1	0.37	1.4	2.7	197	19.8	117
76-77	0.8	45.9	13.1	630	1.98	111.0	0.50	0.62	126.0	1.00	0.10	0.72	13.7	0.36	1.3	2.7	191	18.9	112
77-78	0.8	46.9	13.9	630	2.00	114.5	0.50	0.59	127.3	1.00	0.15	0.72	13.8	0.38	1.3	2.7	194	19.4	111
78-79	1.2	44.0	13.5	680	1.81	108.4	0.65	0.63	131.3	0.95	0.10	0.66	14.0	0.35	3	2.7	194	19.6	111
79-80	1.0	46.6	12.7	690	2.12	117.9	0.50	0.60	129.1	0.90	0.10	0.70	13.9	0.34	1.3	2.7	196	19.0	114
80-81	1.6	46.4	13.7	690	1.98	115.4	0.55	0.57	128.5	0.90	0.10	0.70	13.7	0.35	2.6	2.7	192	19.7	111
81-82	0.8	49.5	13.7	690	2.07	117.9	0.50	0.58	123.9	0.95	0.05	0.76	14.2	0.36	1.6	2.7	199	19.1	113
82-83	0.8	44.0	13.7	720	1.96	109.6	0.45	0.56	120.2	1.00	0.10	0.70	13.2	0.36	1.3	2.7	200	19.4	120
83-84	0.8	44.5	13.7	640	1.88	101.2	0.45	0.53	114.6	1.00	0.05	0.72	12.9	0.36	1.4	2.7	187	18.4	112
84-85	0.8	47.1	13.3	660	1.91	112.5	0.50	0.57	121.5	0.95	0.10	0.70	13.5	0.35	1.3	2.7	200	19.0	117
85-86	0.8	48.1	13.7	670	1.91	113.5	0.45	0.58	125.3	0.90	0.10	0.68	13.4	0.35	1.2	2.7	199	19.3	118
86-87	0.8	47.3	12.5	660	1.94	113.5	0.45	0.58	123.2	0.85	0.10	0.68	12.8	0.34	1.1	2.7	195	18.7	118
87-88	0.8	47.5	14.5	680	1.95	120.5	0.50	0.58	126.6	1.00	0.05	0.74	14.1	0.36	1.3	2.9	201	20.4	121
88-89	0.8	47.4	14.1	650	1.94	113.0	0.50	0.59	124.9	0.90.	0.15	0.66	12.9	0.35	1.2	2.7	200	19.3	114
89-90	0.8	48.4	14.3	670	1.97	115.5	0.50	0.61	126.3	0.95	0.10	0.68	13.4	0.36	1.3	2.7	189	19.7	116
90-91	0.8	47.0	14.3	650	1.94	113.5	0.55	0.63	129.2	1.05	0.10	0.68	13.8	0.36	1.4	2.7	189	19.9	111
91-92	0.8	43.8	13.5	650	1.98	110.5	0.50	0.62	124.0	0.95	0.10	0.68	13.5	0.36	1.3	2.7	192	19.0	113
92-93	0.8	45.0	13.9	650	2.01	113.5	0.55	0.62	122.9	1.00	0.10	0.72	14.1	0.37	1.4	2.7	193	19.6	118
93-94	0.8	44.2	13.1	640	1.95	111.5	0.50	0.58	125.8	1.00	0.15	0.70	13.6	0.36	1.3	2.7	196	18.9	111
94-95	1.4	46.4	13.7	670	1.79	108.9	0.50	0.57	124.7	0.95	0.15	0.68	13.4	0.34	1.6	2.7	196	19.0	113
95-96	0.8	46.2	13.3	660	1.73	105.9	0.50	0.56	121.6	0.95	0.10	0.66	13.3	0.33	1.7	2.7	189	18.6	108

Table 15 continued

Depth cm	Mo ppm	Ni ppm	Nb ppm	P ppm	K %	Rb ppm	Ag ppm	Na %	Sr ppm	Ta ppm	Te ppm	Tl ppm	Th ppm	Ti %	W ppm	U ppm	V ppm	Y ppm	Zn ppm
96-97	0.8	44.8	12.5	650	1.93	113.4	0.50	0.50	116.0	0.85	0.15	0.70	12.9	0.32	1.6	2.5	183	18.4	101
97-98	0.8	45.0	12.5	690	2.11	116.4	0.65	0.52	126.8	0.90	0.10	0.72	14.0	0.35	1.4	2.7	200	18.9	115
98-99	1.0	44.6	12.7	690	1.93	112.8	0.45	0.59	125.2	0.90	0.05	0.68	12.2	0.34	1.3	2.5	185	18.5	110
99-100	1.0	45.4	14.1	720	1.94	118.8	0.50	0.62	126.6	1.05	0.10	0.72	13.9	0.35	1.4	2.9	186	20.3	114
100-101	0.8	45.1	13.1	640	1.87	108.0	0.50	0.57	120.9	0.90	0.10	0.68	12.7	0.34	1.2	2.7	193	18.5	111
101-102	1.2	53.8	13.7	690	1.90	112.0	0.50	0.59	127.3	0.90	0.10	0.68	13.4	0.35	1.4	2.7	199	19.2	118
102-103	0.8	45.5	13.5	670	1.89	115.5	0.55	0.58	125.2	0.95	0.10	0.68	13.4	0.34	1.3	2.7	197	19.6	114
103-104	0.8	45.7	13.3	670	1.90	110.5	0.55	0.60	123.5	0.90	0.10	0.70	13.3	0.34	1.2	2.7	193	19.2	117
104-105	0.8	49.7	14.1	680	1.96	116.0	0.75	0.60	122.9	0.95	0.10	0.66	13.3	0.36	1.3	2.7	200	19.9	122
105-106	1.0	49.2	14.7	670	1.93	115.0	0.50	0.58	123.8	0.95	0.15	0.68	13.6	0.36	1.3	2.7	195	20.2	120
106-107	0.8	43.8	13.3	630	1.91	111.0	0.55	0.57	123.6	0.90	0.05	0.70	13.0	0.35	1.3	2.7	194	19.0	117
107-108	0.8	44.0	13.7	630	1.94	110.5	0.50	0.60	120.5	0.95	0.10	0.70	13.3	0.36	1.4	2.7	195	19.1	109
108-109	0.8	45.4	13.5	630	1.93	110.5	0.55	0.58	121.9	1.00	0.10	0.70	13.5	0.36	1.4	2.7	195	18.8	114
109-110	0.8	47.0	13.1	660	2.00	115.0	0.50	0.58	126.2	0.95	0.10	0.76	14.0	0.36	1.3	2.7	202	19.3	117
110-111	3.0	42.9	13.3	660	1.99	110.4	0.70	0.56	123.2	0.90	0.15	0.68	13.4	0.34	1.4	2.7	197	18.5	109
111-112	0.8	43.1	13.3	700	1.87	106.4	0.55	0.60	127.0	1.00	0.05	0.68	13.7	0.36	1.8	2.7	203	18.5	116
112-113	0.8	47.8	13.5	700	2.05	114.4	0.55	0.55	129.4	0.90	0.05	0.70	13.5	0.35	1.6	2.5	199	19.3	111
113-114	1.0	50.7	13.7	710	1.86	108.9	0.65	0.62	130.3	0.95	0.10	0.68	14.2	0.37	1.5	2.5	199	20.2	111
114-115	1.0	46.8	13.3	710	1.93	123.3	0.45	0.61	127.7	0.95	0.10	0.70	14.0	0.34	1.2	2.7	185	20.7	114
115-116	1.0	43.8	13.3	730	1.99	116.8	0.45	0.61	124.0	1.00	0.10	0.72	13.9	0.36	1.3	2.9	191	19.1	116
116-117	0.8	44.6	13.3	650	1.90	107.5	0.50	0.60	120.4	0.95	0.05	0.68	13.3	0.35	1.3	2.7	185	18.3	113
117-118	1.4	53.9	14.1	680	1.94	115.5	0.50	0.60	122.8	0.95	0.10	0.72	13.6	0.35	1.3	2.9	188	19.6	118
118-119	0.8	44.1	12.9	640	1.91	110.0	0.45	0.58	121.1	0.85	0.10	0.64	12.4	0.35	1.2	2.7	192	18.4	118
119-120	0.6	35.3	9.9	610	1.92	87.7	0.35	0.58	102.5	0.65	0.05	0.50	9.7	0.33	0.9	2.1	183	14.4	113
120-121	1.0	47.1	14.1	620	1.94	118.0	0.60	0.58	122.4	0.95	0.15	0.68	13.1	0.34	1.3	2.9	193	19.4	115
121-122	0.8	43.1	13.3	640	1.93	112.0	0.55	0.57	122.2	0.90	0.15	0.66	12.8	0.34	1.2	2.7	195	18.4	118
122-123	0.8	45.3	13.5	640	1.94	115.5	0.50	0.58	124.1	0.95	0.10	0.72	13.2	0.35	1.3	2.7	196	19.1	115
123-124	0.8	44.8	13.7	630	1.94	115.5	0.50	0.58	124.5	1.00	0.10	0.72	13.7	0.36	1.3	2.9	193	19.2	113
124-125	0.6	35.6	11.1	510	1.61	91.3	0.40	0.49	100.9	0.80	0.10	0.56	10.9	0.30	1.1	2.3	157	15.5	96
125-126	0.8	44.4	12.7	650	1.99	112.5	0.50	0.56	125.2	0.90	0.05	0.70	13.2	0.35	1.3	2.7	202	18.6	113
126-127	14.0	43.3	13.5	660	1.96	110.9	1.60	0.55	123.1	0.90	0.15	0.74	12.6	0.34	2.3	2.7	191	18.7	111
127-128	1.2	41.1	13.1	660	1.91	106.9	0.70	0.56	120.5	0.90	0.10	0.68	12.7	0.35	2.1	2.7	192	18.3	110

Table 15 continued

Depth cm	Mo ppm	Ni ppm	Nb ppm	P ppm	K %	Rb ppm	Ag ppm	Na %	Sr ppm	Ta ppm	Te ppm	Tl ppm	Th ppm	Ti %	W ppm	U ppm	V ppm	Y ppm	Zn ppm
128-129	1.4	46.3	13.3	700	2.13	116.9	0.55	0.57	127.4	0.90	0.05	0.72	13.5	0.35	1.3	2.7	204	19.1	114
129-130	0.8	45.2	12.9	680	2.08	119.9	0.55	0.55	126.2	0.95	0.15	0.74	13.8	0.33	2.8	2.7	194	18.9	113
130-131	1.6	50.5	12.7	680	1.91	109.4	0.45	0.56	116.1	0.90	0.05	0.72	12.6	0.34	1.3	2.7	179	18.7	112
131-132	0.8	40.8	13.1	680	1.97	120.8	0.45	0.58	118.5	1.00	0.05	0.74	13.5	0.35	1.2	2.9	184	19.1	118
132-133	0.8	43.4	13.1	630	1.89	110.0	0.50	0.56	119.4	0.95	0.15	0.68	13.1	0.35	1.3	2.9	195	18.4	115
133-134	1.4	52.2	13.1	670	1.89	108.5	0.50	0.59	123.2	0.90	0.05	0.64	12.4	0.34	1.3	2.7	191	18.2	118
134-135	1.0	50.9	13.3	640	1.90	110.5	0.50	0.61	125.1	0.90	0.10	0.66	13.0	0.35	1.3	2.7	183	19.2	112
135-136	1.0	47.9	13.3	660	1.92	114.5	0.55	0.59	125.5	0.90	0.10	0.68	12.9	0.34	1.3	2.7	192	18.9	117
136-137	0.8	47.7	13.7	640	1.98	119.5	0.50	0.57	123.8	0.95	0.10	0.70	13.3	0.35	1.3	2.7	204	19.3	121
137-138	0.8	47.3	14.1	630	2.02	120.5	0.45	0.58	126.2	0.95	0.15	0.72	13.2	0.36	1.3	2.7	206	19.7	122
138-139	0.8	47.7	14.3	650	1.97	119.0	0.50	0.61	128.6	0.95	0.15	0.68	13.4	0.36	1.3	2.7	190	19.8	117
139-140	0.8	47.3	14.3	650	2.00	118.0	0.60	0.62	129.4	1.00	0.15	0.72	14.3	0.37	1.3	2.9	198	19.9	117
140-141	0.4	26.0	7.7	360	1.20	63.9	0.30	0.39	74.0	0.55	0.05	0.40	7.9	0.22	0.7	1.7	113	10.8	68
141-142	0.8	47.4	13.3	640	2.02	113.5	0.55	0.62	130.7	0.95	0.15	0.76	14.0	0.37	1.3	2.9	194	19.2	112
142-143	1.4	45.1	13.7	680	2.00	108.9	0.55	0.60	129.6	0.95	0.05	0.68	13.4	0.36	1.6	2.9	189	19.2	113
143-144	1.0	46.1	13.1	660	1.85	109.4	0.55	0.62	130.0	0.95	0.10	0.68	13.7	0.35	5.5	2.7	185	19.0	108
144-145	1.2	50.2	13.9	730	2.13	114.9	0.55	0.63	130.8	0.95	0.10	0.70	13.7	0.37	1.4	2.9	191	19.4	112
145-146	3.0	42.7	13.7	780	2.01	110.9	0.55	0.63	130.2	0.85	0.10	0.66	13.4	0.36	27.4	2.5	186	19.3	109
146-147	0.8	42.8	13.9	720	1.91	103.0	0.45	0.58	120.6	0.95	0.10	0.66	12.4	0.36	1.3	2.7	176	18.9	116
14-148	0.8	42.8	14.1	710	1.93	113.8	0.45	0.62	122.9	1.05	0.15	0.72	13.7	0.36	1.4	2.9	183	19.4	110
148-149	0.8	46.6	13.3	670	1.92	110.0	0.50	0.59	125.3	0.95	0.10	0.70	13.3	0.36	3.8	2.7	193	18.5	117
149-150	0.6	33.8	10.1	620	1.86	81.5	0.35	0.61	104.2	0.70	0.05	0.50	10.0	0.34	1	2.1	176	14.2	105
150-151	0.8	47.6	13.3	660	1.91	112.0	0.50	0.61	127.6	0.90	0.10	0.68	13.0	0.34	1.2	2.7	186	19.1	112
151-152	0.8	45.3	12.5	640	1.89	106.5	0.45	0.60	123.9	0.80	0.05	0.62	12.1	0.33	1.2	2.5	188	18.2	113
152-153	0.8	47.3	14.5	650	1.96	118.5	0.55	0.62	129.3	0.95	0.10	0.70	13.9	0.36	1.3	2.9	187	20.5	115
153-154	0.8	46.3	13.7	630	1.97	112.0	0.50	0.62	126.7	0.90	0.10	0.66	13.2	0.35	1.2	2.7	197	19.1	116
154-155	0.8	47.1	13.5	630	1.93	115.5	0.45	0.59	125.0	0.95	0.05	0.68	13.2	0.35	1.3	2.5	187	19.0	115
155-156	0.8	46.7	14.1	640	1.98	115.5	0.50	0.64	129.9	1.00	0.10	0.72	14.3	0.37	1.3	2.9	189	20.2	115
156-157	0.8	44.9	13.9	670	2.01	113.0	0.55	0.67	134.8	1.00	0.10	0.72	14.3	0.37	1.3	2.9	184	19.7	110
157-158	0.8	48.4	13.7	690	2.01	115.5	0.55	0.64	134.1	1.00	0.10	0.72	14.4	0.38	1.4	2.9	190	19.8	114
Mean	1.1	45.8	13.4	684	1.94	112.9	0.56	0.59	124.0	0.94	0.10	0.69	13.4	0.35	1.6	2.7	192	19.1	116
St.Dev.	1.21	3.25	0.82	72.43	0.09	6.98	0.16	0.04	6.43	0.07	0.03	0.04	0.85	0.02	2.14	0.19	9.41	1.08	6.97

Table 16. Geochemical markers in cores 3, 4 and 8

Marker	Depth (cm) Core 3	Core 4	Core 8
Ca	30	30	30
Ca	46	41	46
Ca	69	76	69
Ca	122	129	119
Mg	-	31	30
Mg	-	109	98
Cd	15	18	20
Cd	48	45	-

Table 17. Degree of core top concentration increases for select elements in Lake Winnipeg 99-900 cores 3, 4 and 8

	Ag (ppm)	Cd (ppm)	Cu (ppm)	Hg (ppb)	Pb (ppm)	P (ppm)	Sb (ppm)	U (ppm)	Zn (ppm)
Core 3 Mean below increase	0.16	0.54	34	n/a	21	700	0.71	2.9	145
Core 3 Maxima	0.30	0.70	40	n/a	29	1000	0.96	3.5	169
Core 3 Increase	**1.9**	**1.3**	**1.2**	**n/a**	**1.4**	**1.4**	**1.4**	**1.2**	**1.2**
Core 4 Mean below increase	0.56	0.47	28	41	20	710	n/a	2.7	125
Core 4 Maxima	0.70	0.60	33	110	29	1090	n/a	3.4	144
Core 4 Increase	**1.3**	**1.3**	**1.2**	**2.7**	**1.5**	**1.5**	**n/a**	**1.3**	**1.2**
Core 8 Mean below increase	0.50	0.51	26	50	20.0	660	n/a	2.7	114
Core 8 Maxima	1.25	0.60	30	120	28.5	950	n/a	3.3	135
Core 8 Increase	**2.5**	**1.2**	**1.2**	**2.4**	**1.4**	**1.4**	**n/a**	**1.2**	**1.2**

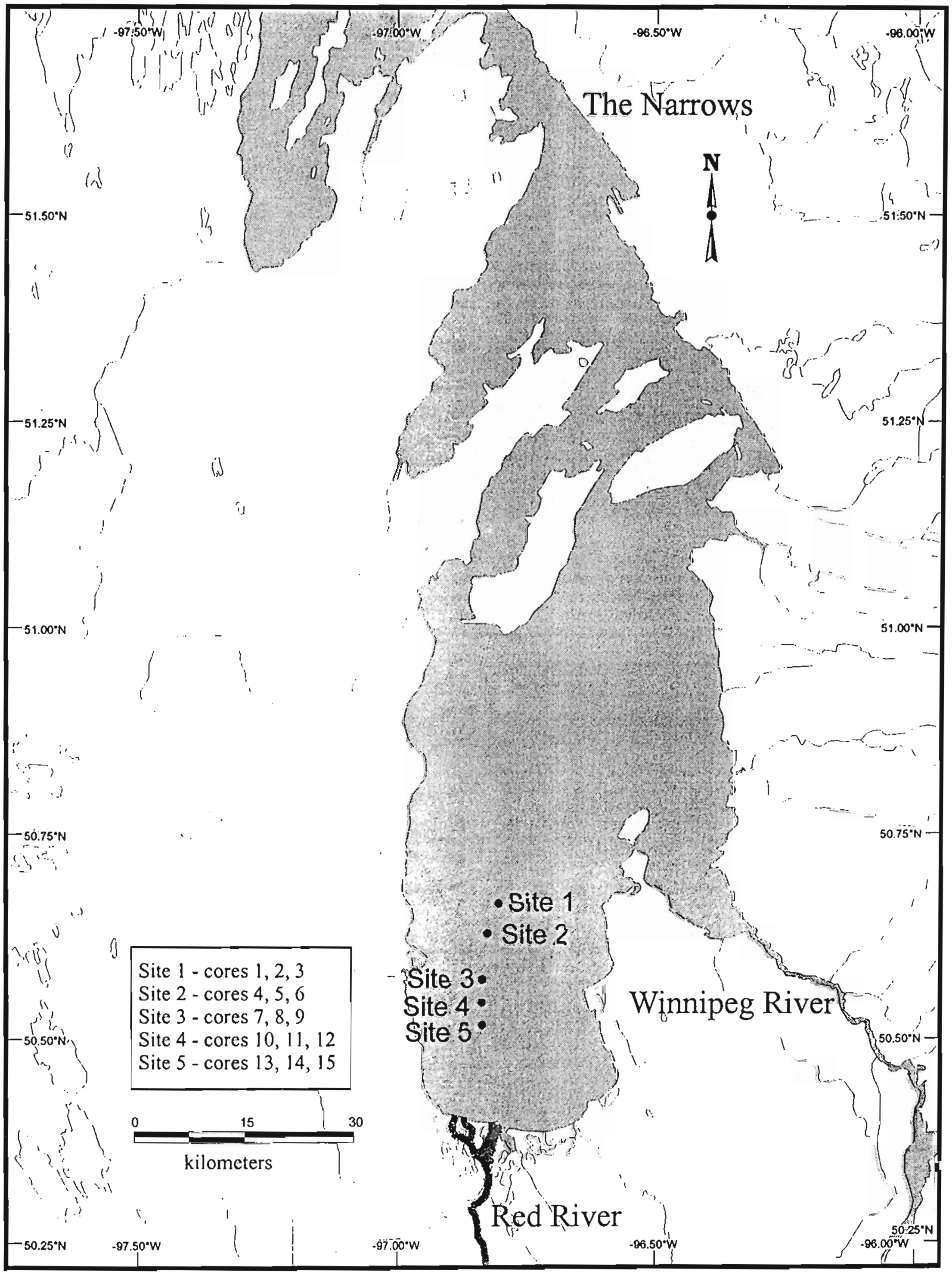


Figure 1. Map of southern Lake Winnipeg showing locations of coring sites

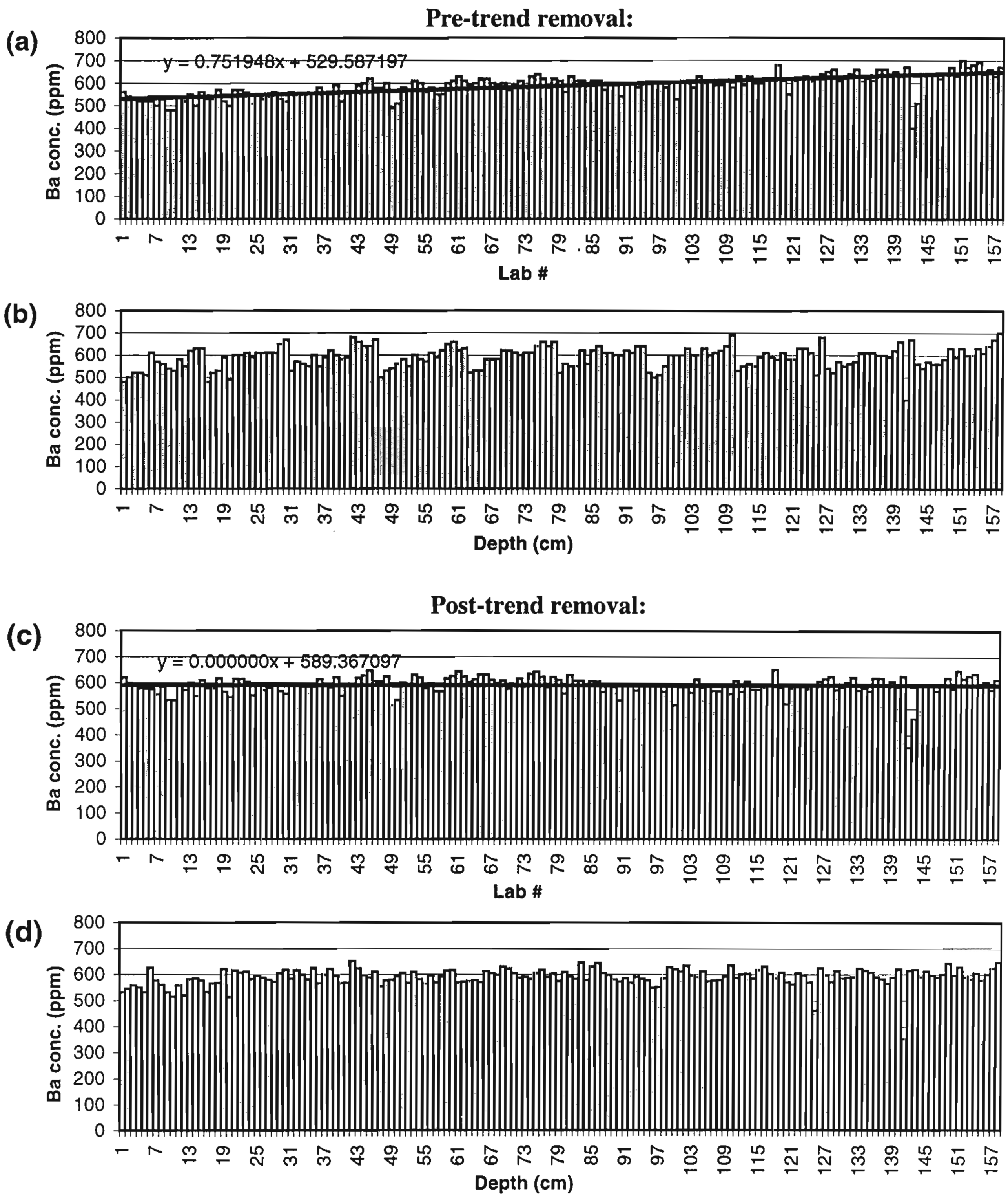
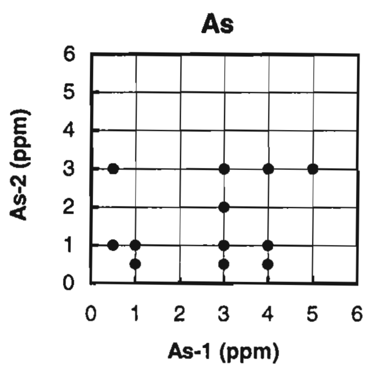


Figure 2. Example of trend removal for Ba in Lake Winnipeg 99-900 core 8. For data in (a) analytical order prior to trend removal, (b) depth order prior to trend removal, (c) analytical order following trend removal, and (d) depth order following trend removal.

Figure 3. First (-1) versus second (-2) analysis of duplicate samples for inorganic geochemistry for Lake Winnipeg 99-900 cores 4 and 8

Cores 4 and 8
Duplicate samples
Analytical method: AAS-HYDRIDE/EDL
Decomposition: Aqua regia
n = 23



Cores 4 and 8
Duplicate samples
Analytical method: CV-AAS
Decomposition: Aqua regia
n = 23

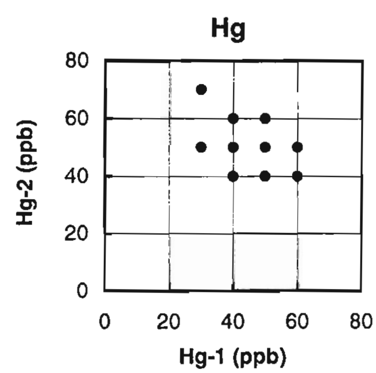
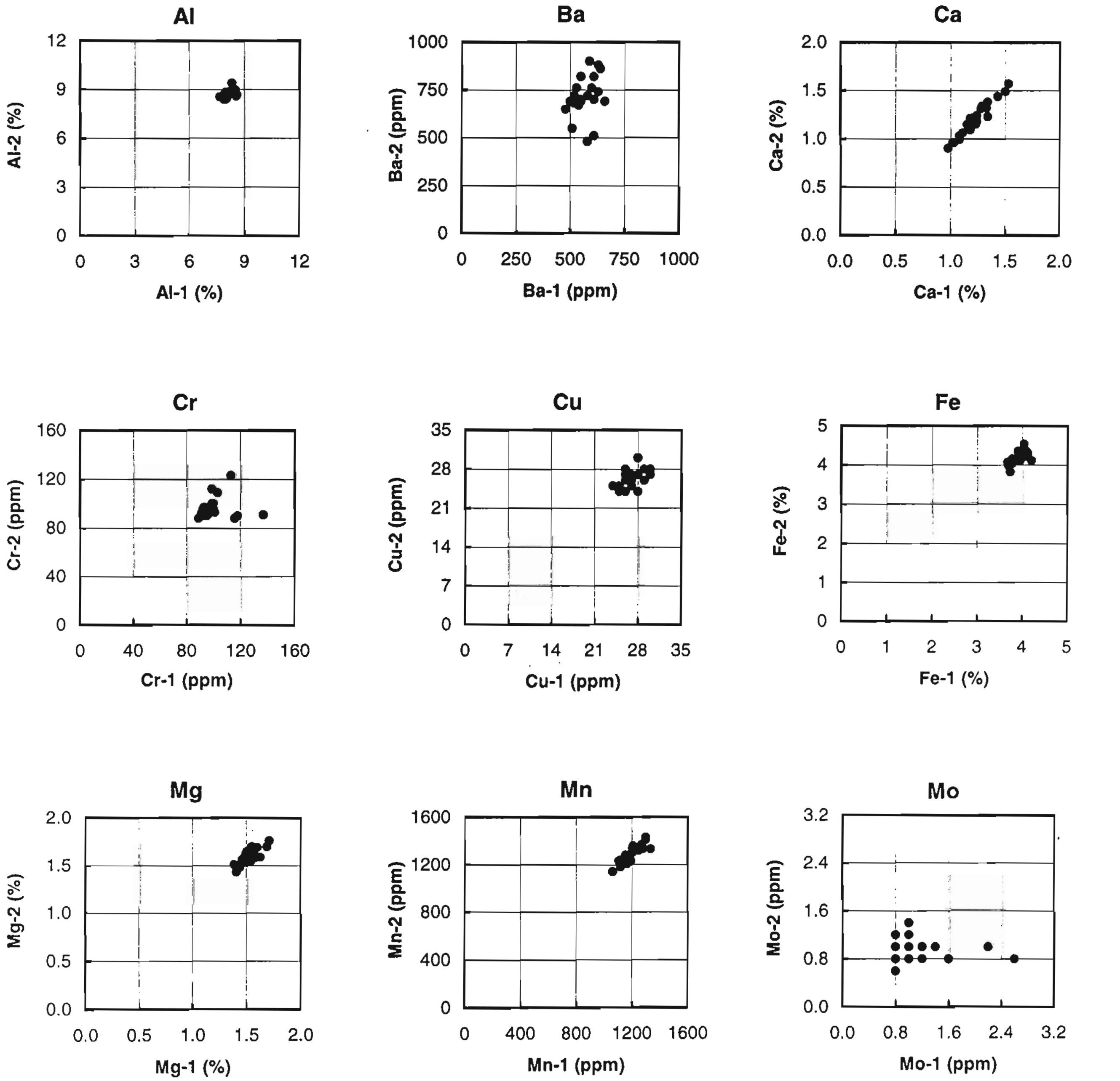


Figure 3 continued

Cores 4 and 8
Duplicate samples
Analytical method: ICP-ES
Decomposition: HF-HNO3-HClO4 (near total)
n = 23



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Cores 4 and 8
Duplicate samples
Analytical method: ICP-ES
Decomposition: HF-HNO3-HClO4 (near total)
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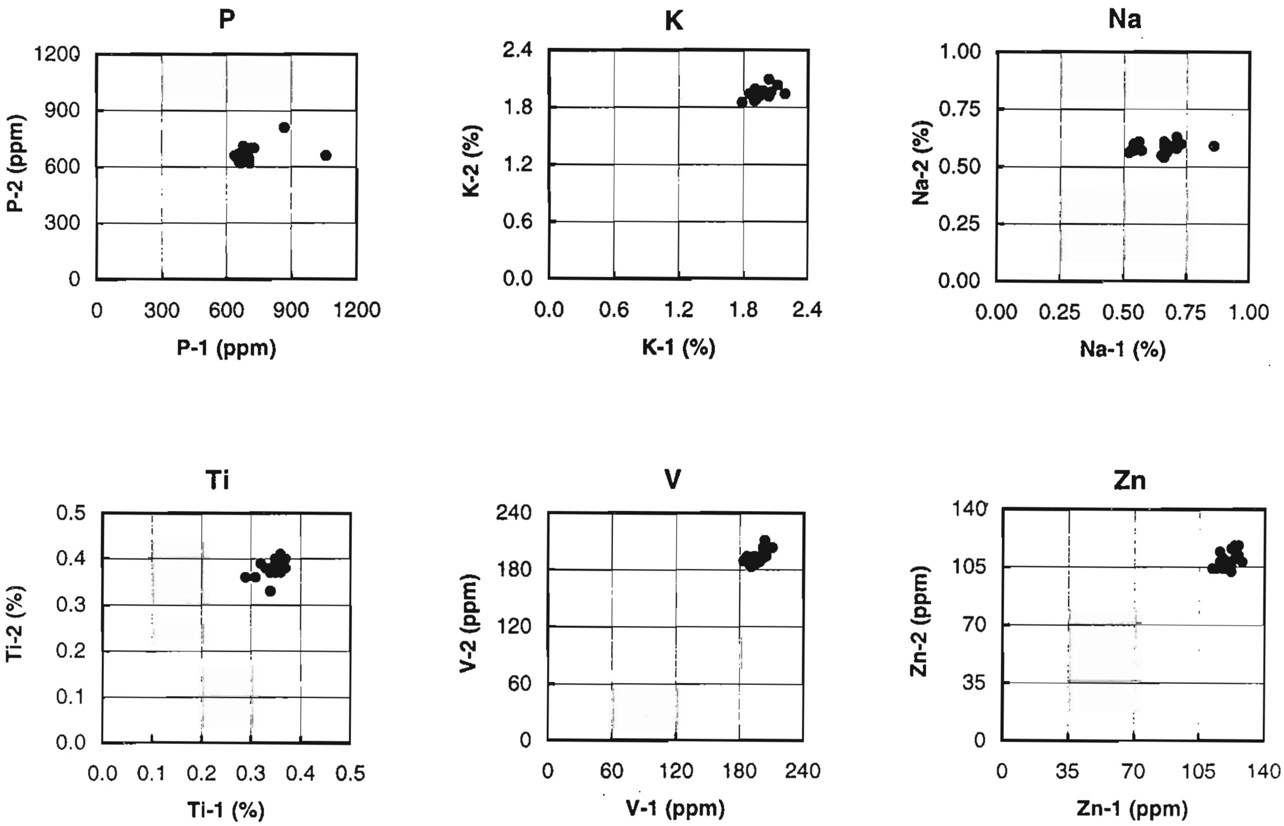

Figure 3 continued

Cores 4 and 8
Duplicate samples
Analytical method: ICP-MS
Decomposition: HF-HNO3-HClO4 (near total)
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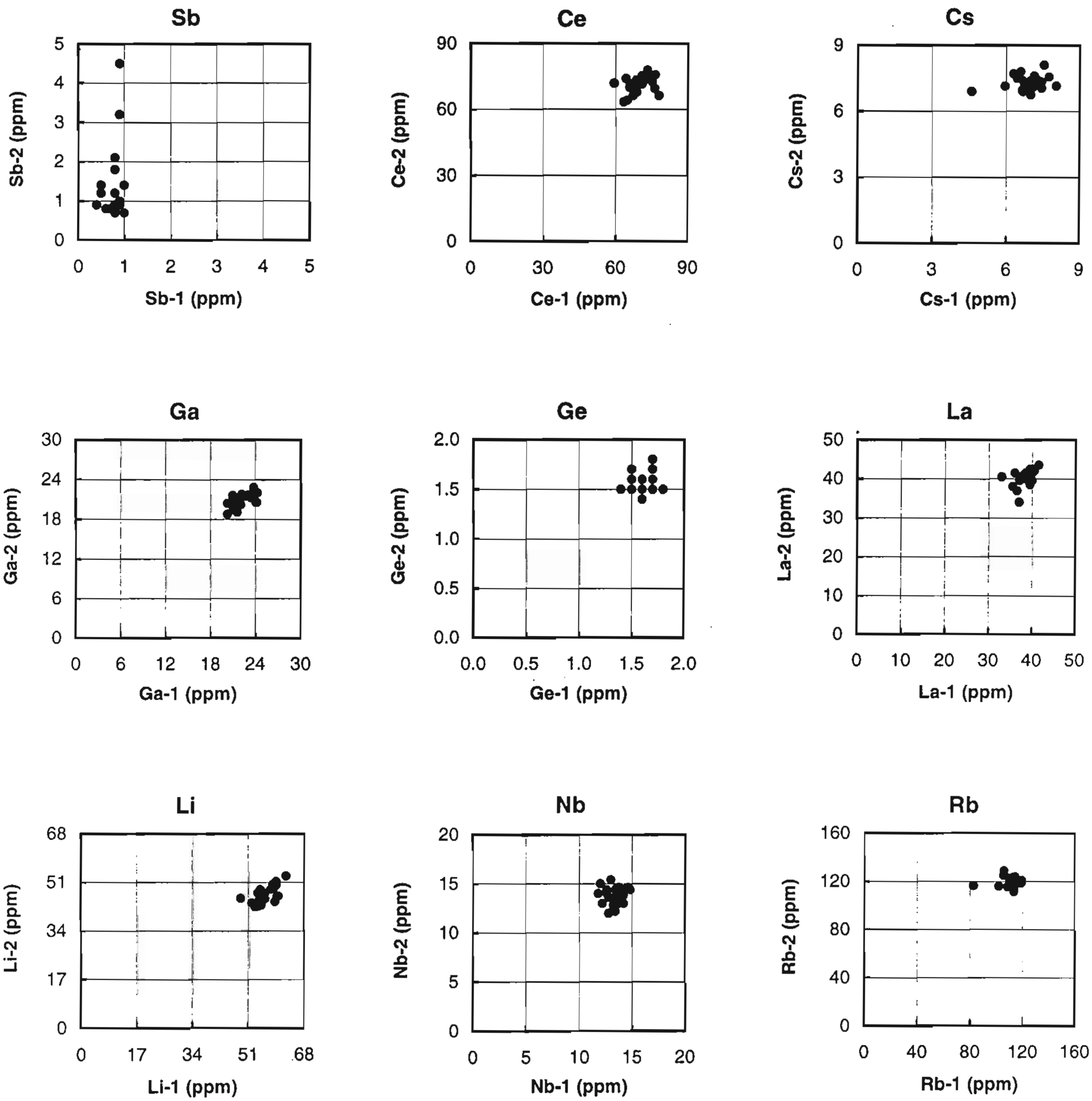


Figure 3 continued

Cores 4 and 8
Duplicate samples
Analytical method: ICP-MS
Decomposition: HF-HNO3-HClO4 (near total)
n = 23

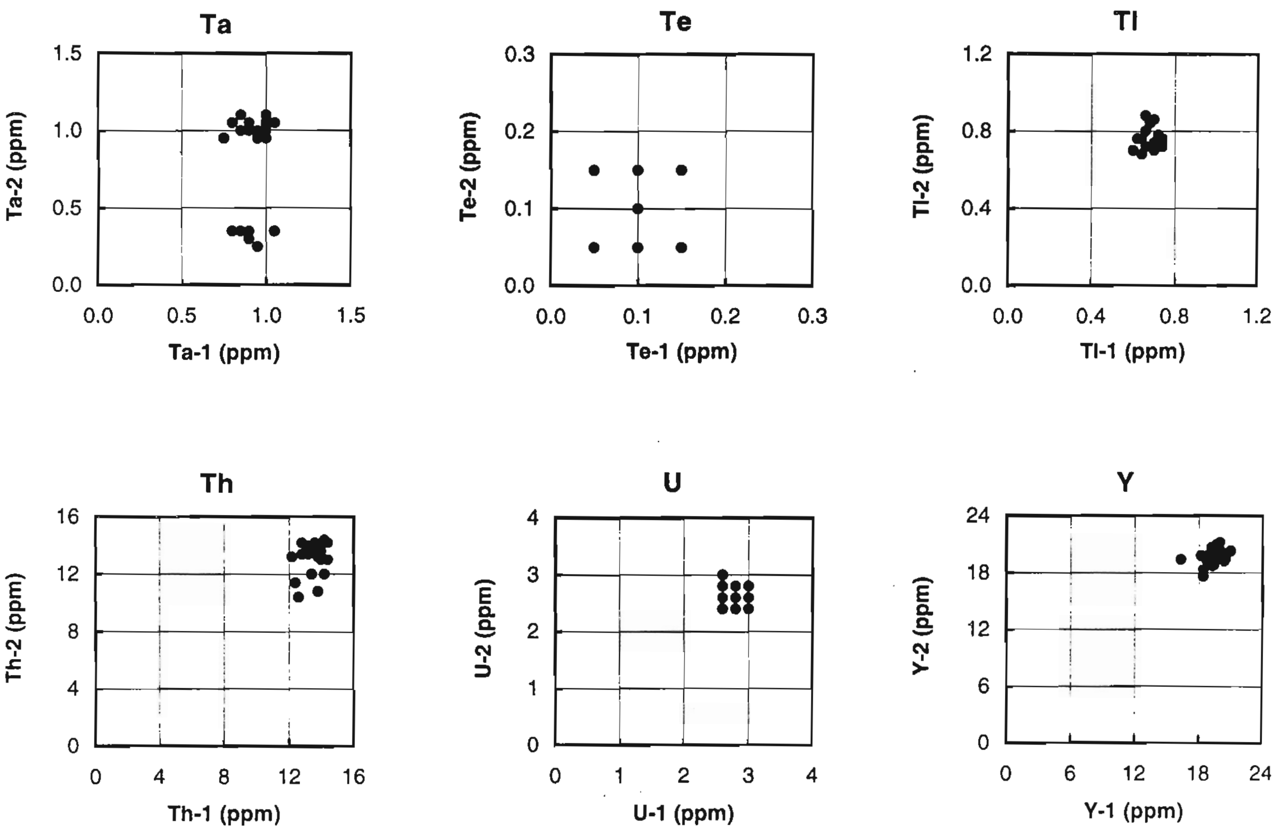
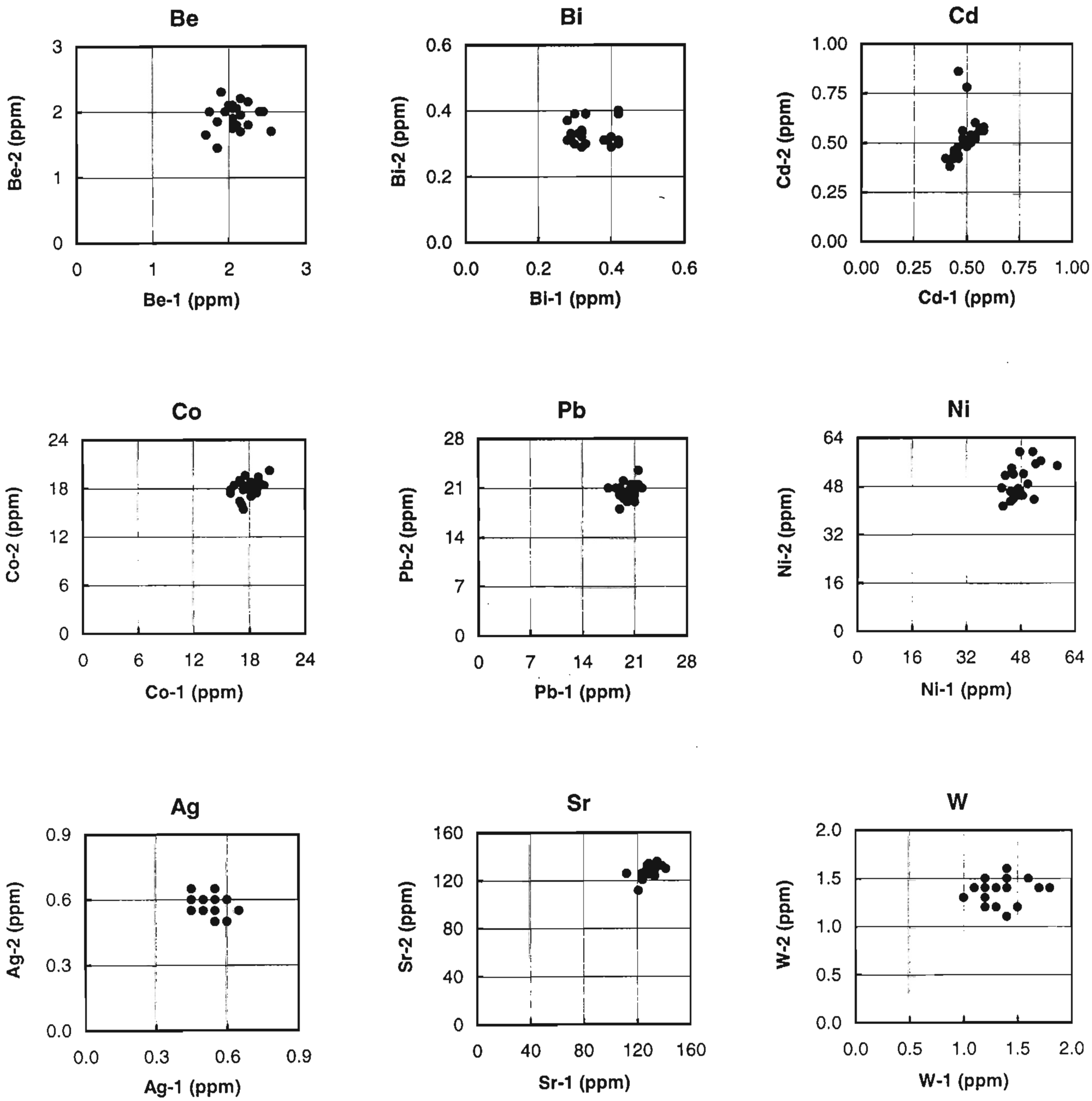


Figure 3 continued

Cores 4 and 8
Duplicate samples
Analytical method: ICP-MS/ICP-ES
Decomposition: HF-HNO3-HClO4 (near total)
n = 23



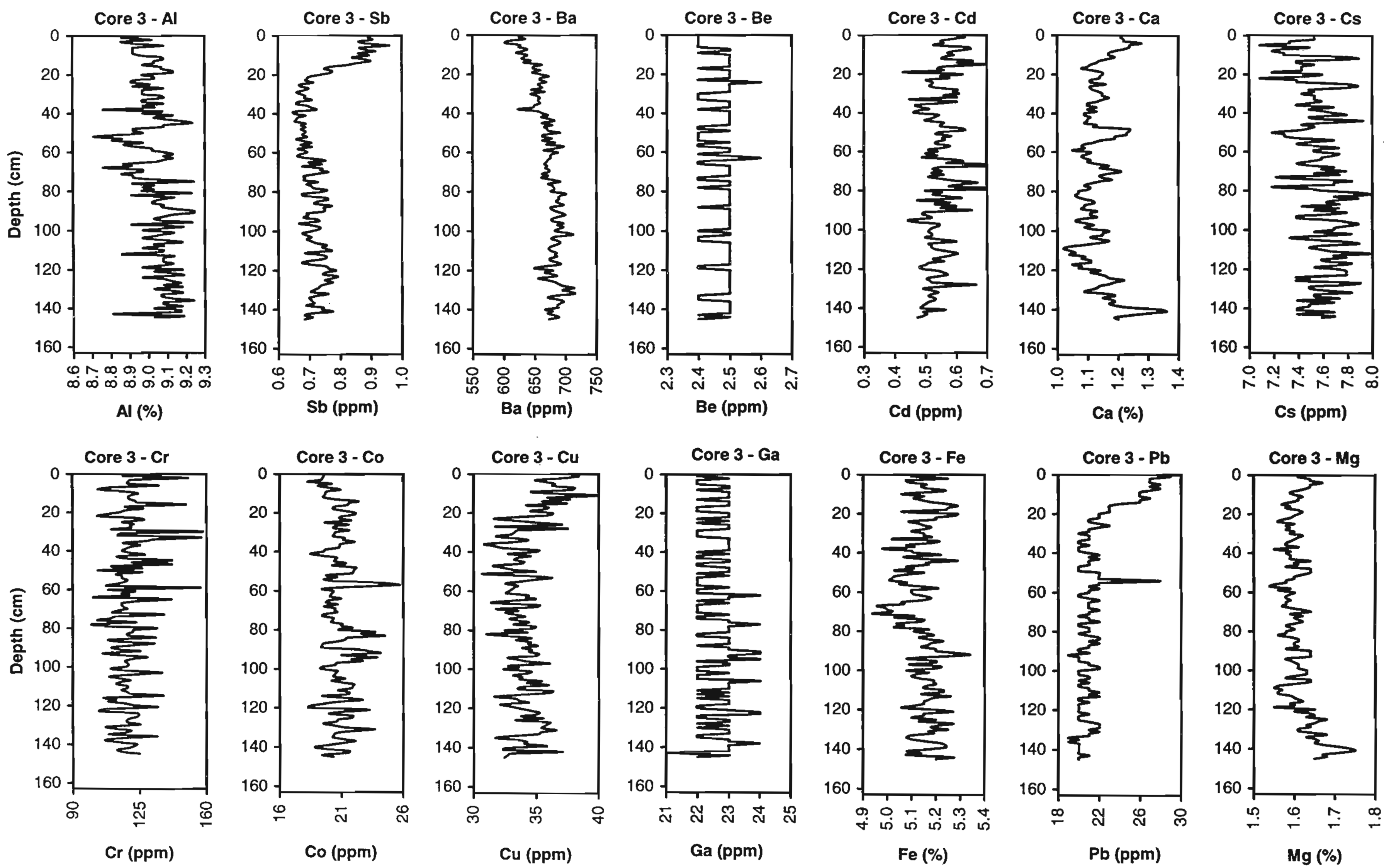


Figure 4. Down-core variations in element concentrations for Lake Winnipeg 99-900 core 3

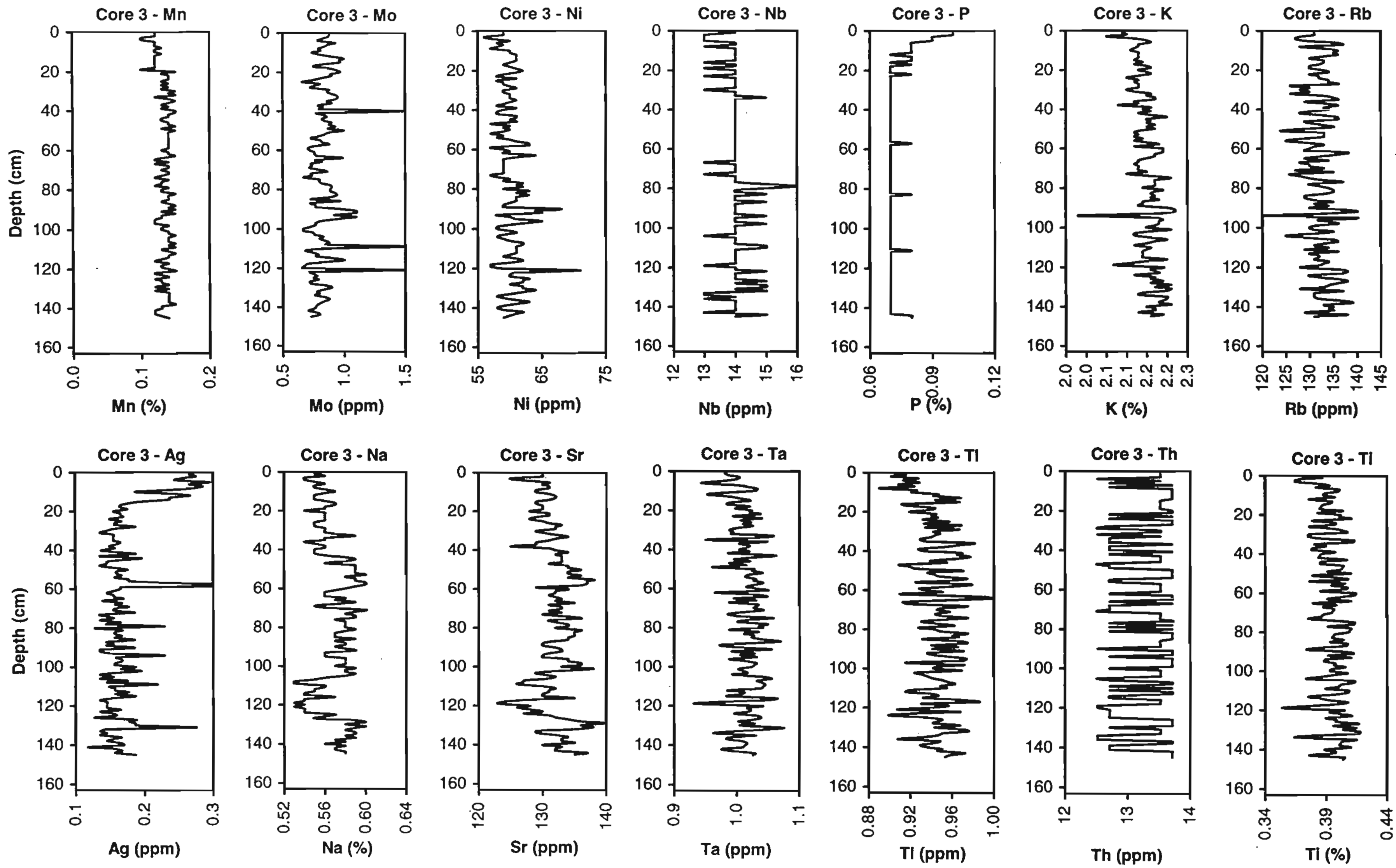
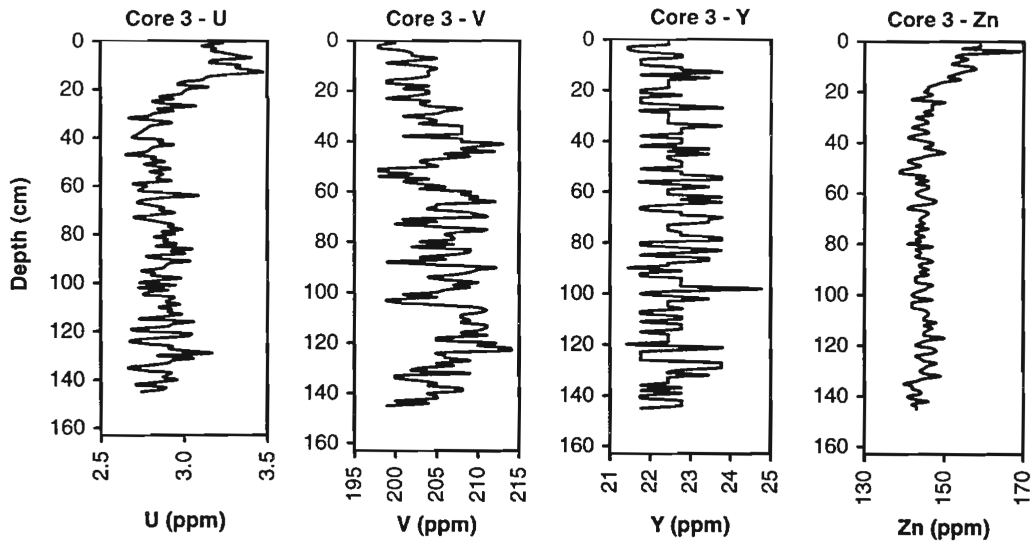


Figure 4 continued



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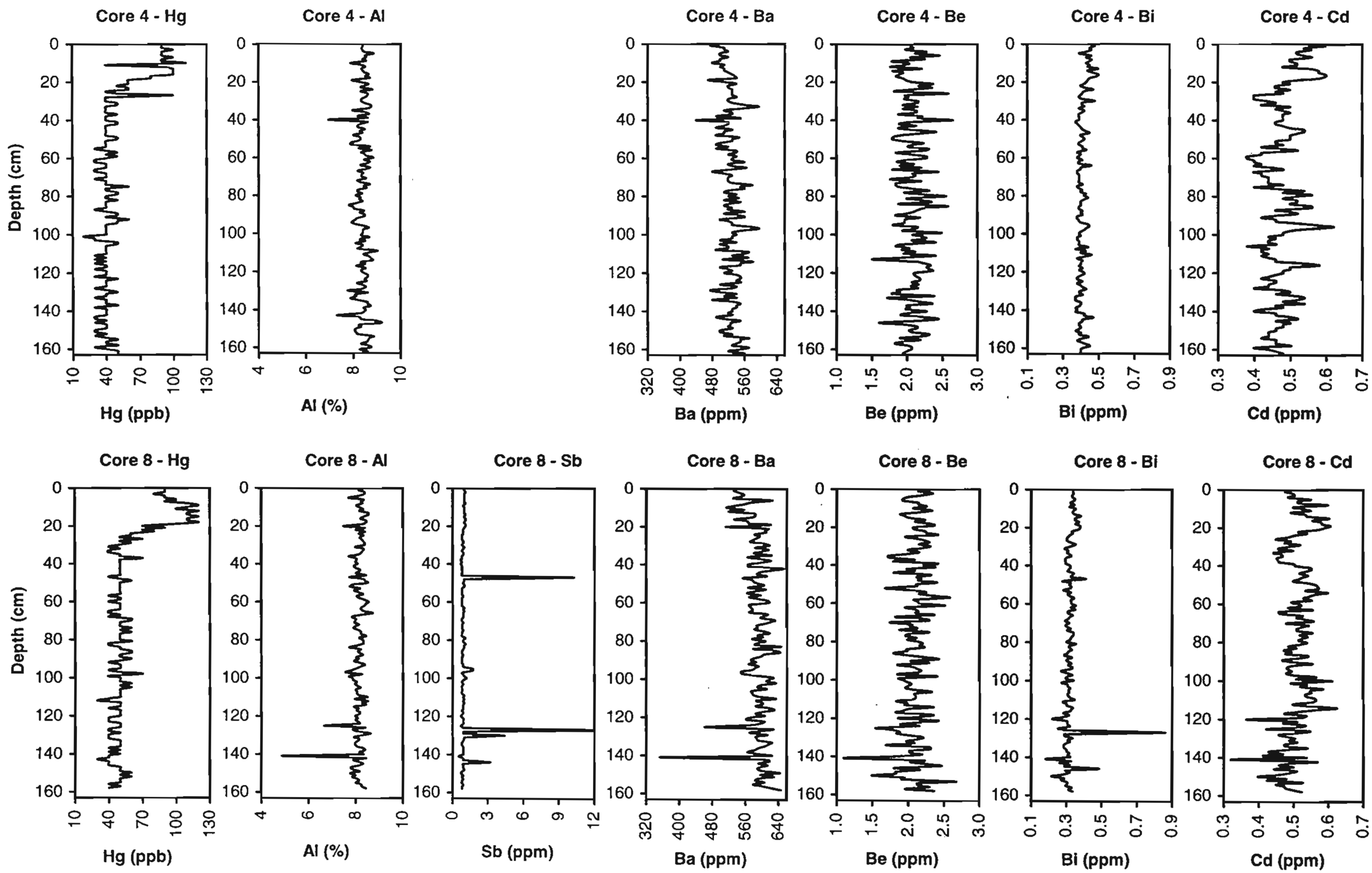
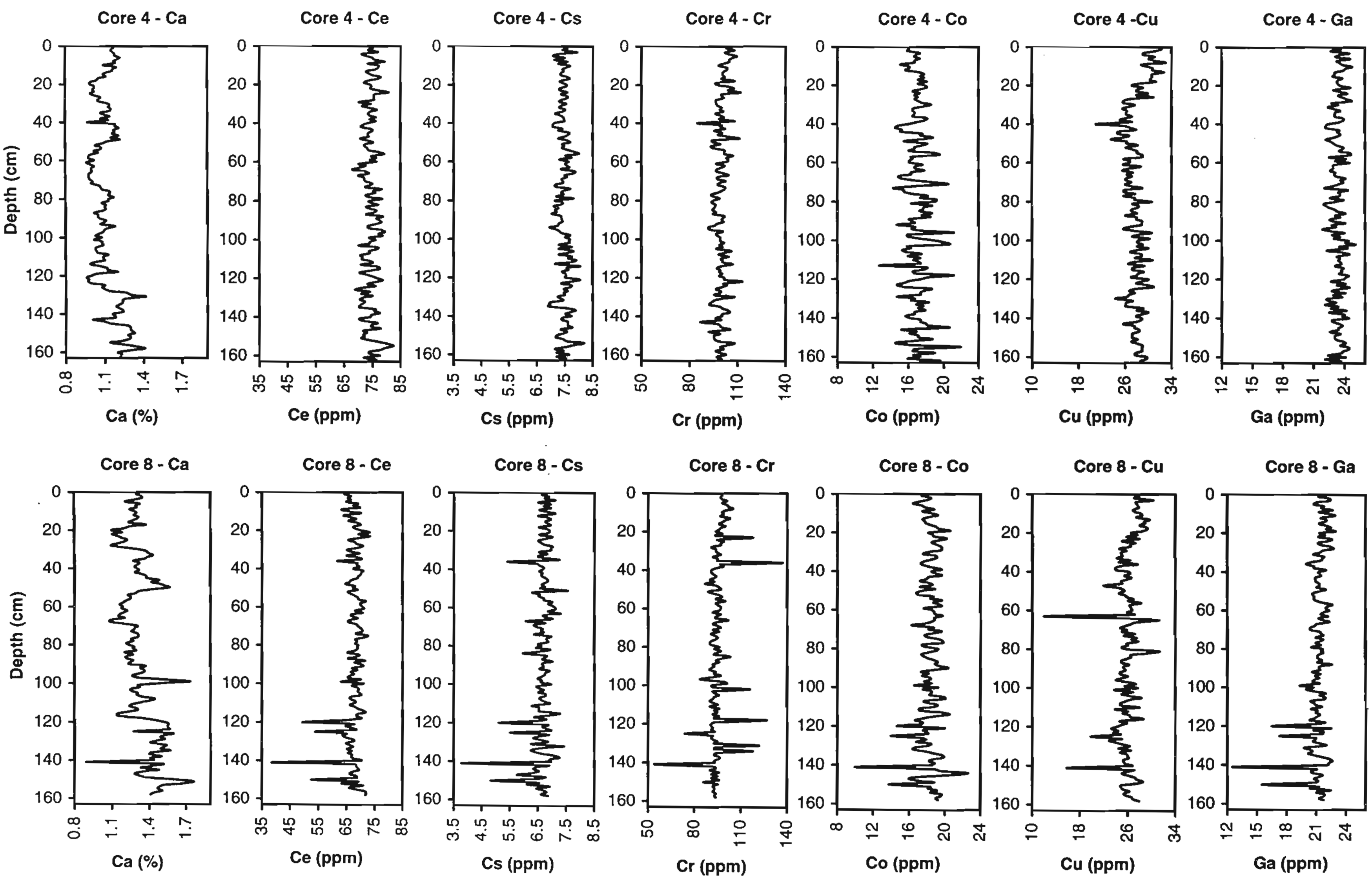


Figure 5. Down-core variations in element concentrations for Lake Winnipeg 99-900 cores 4 and 8



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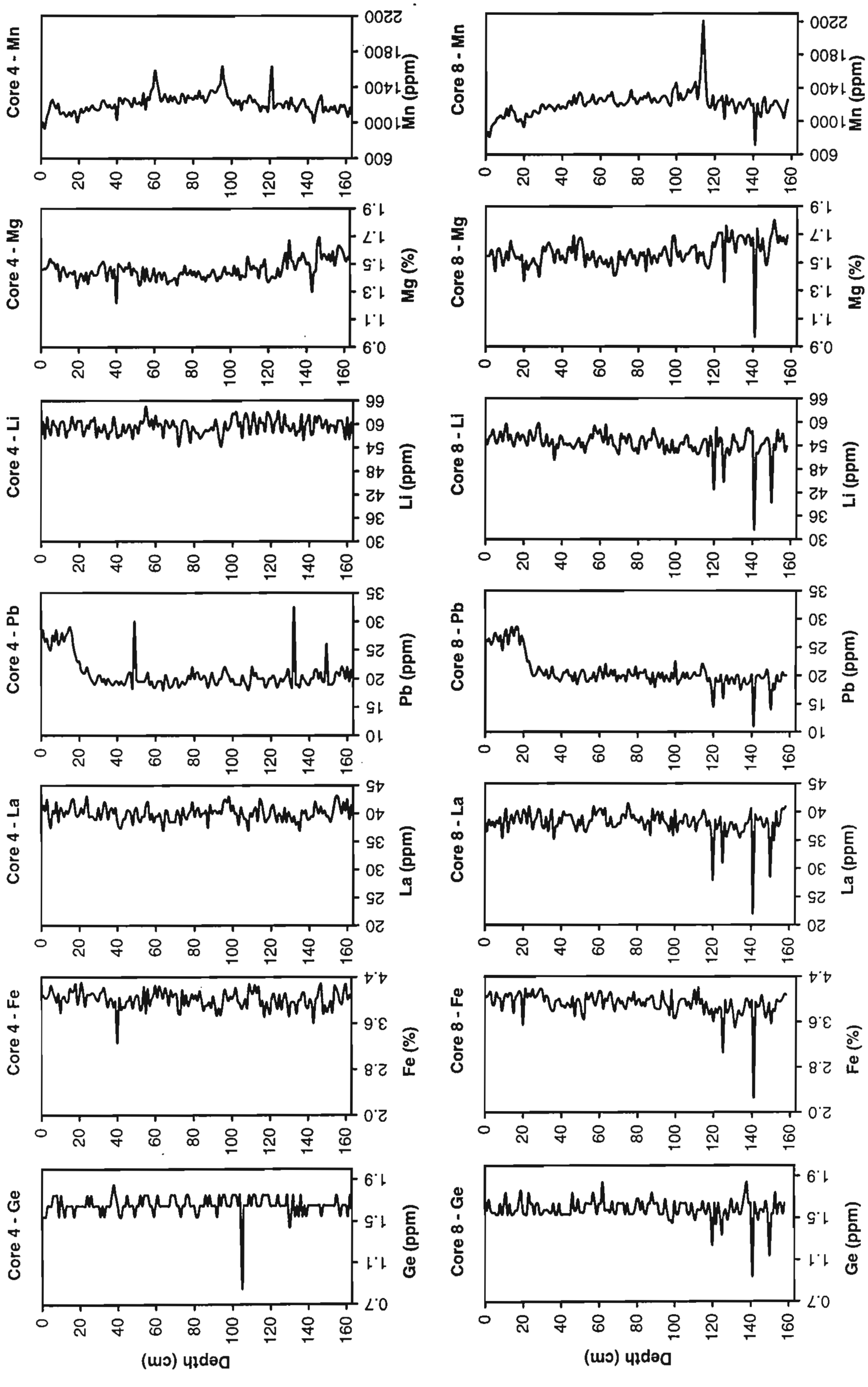

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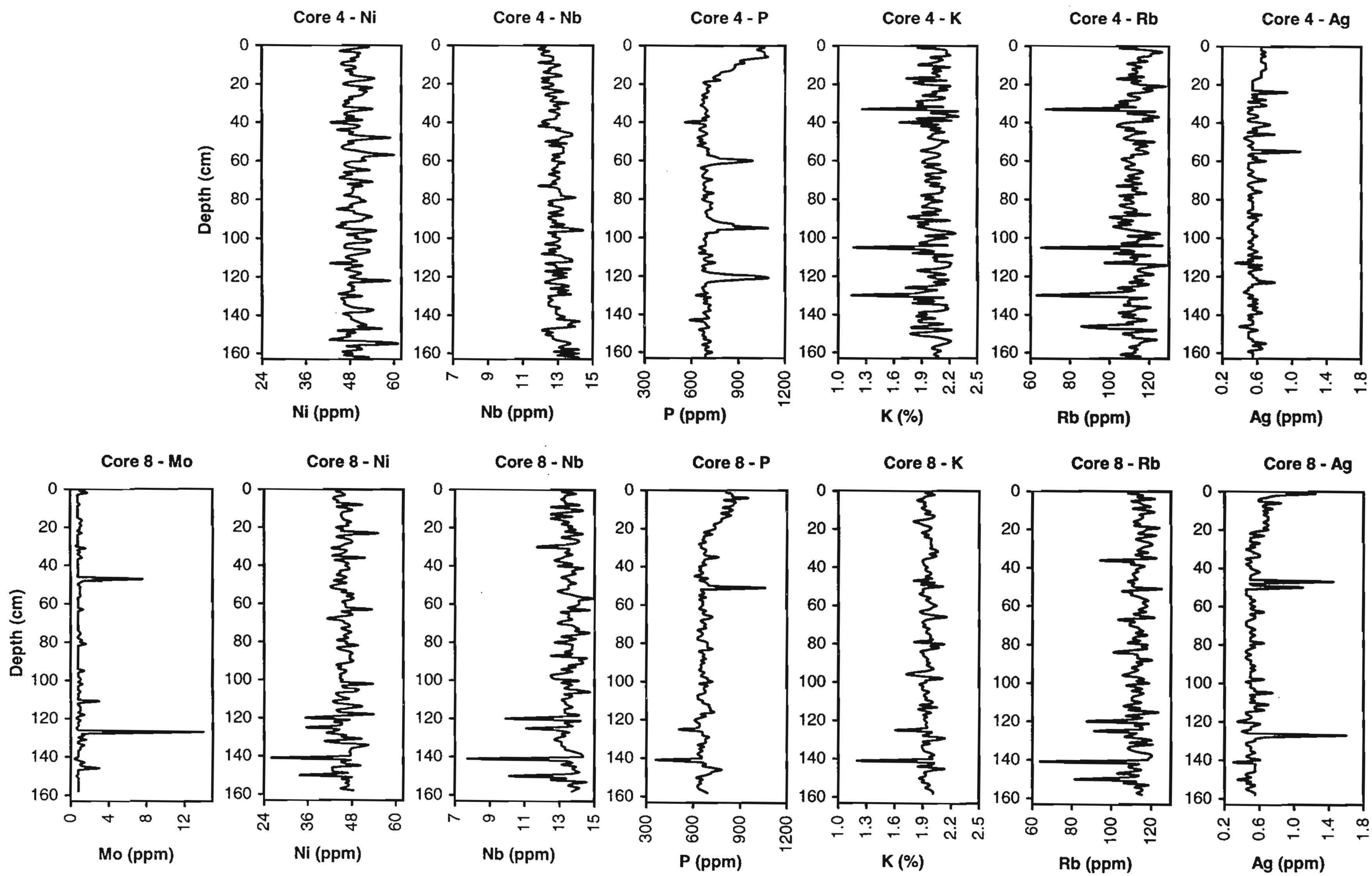

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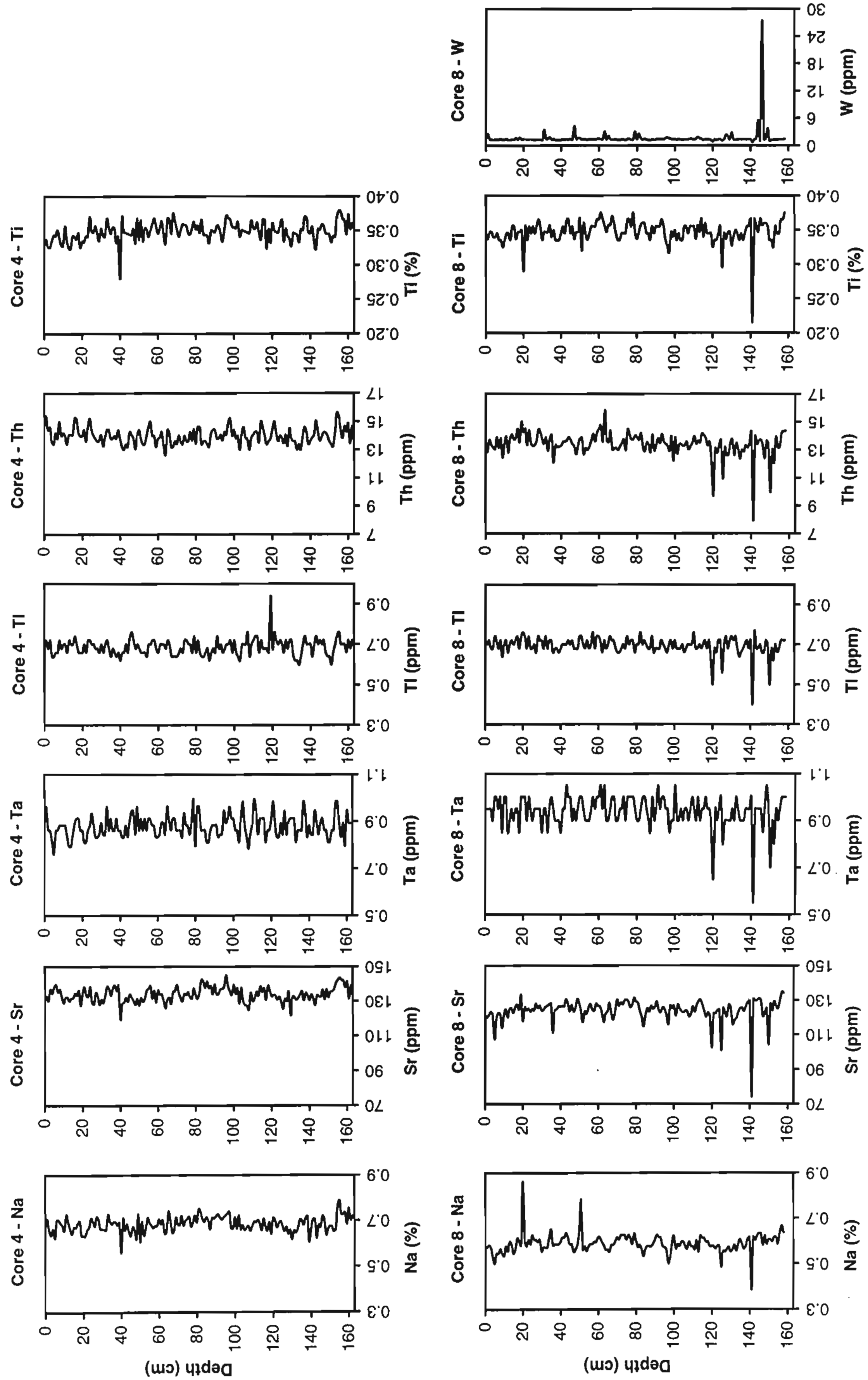

Figure 5 continued

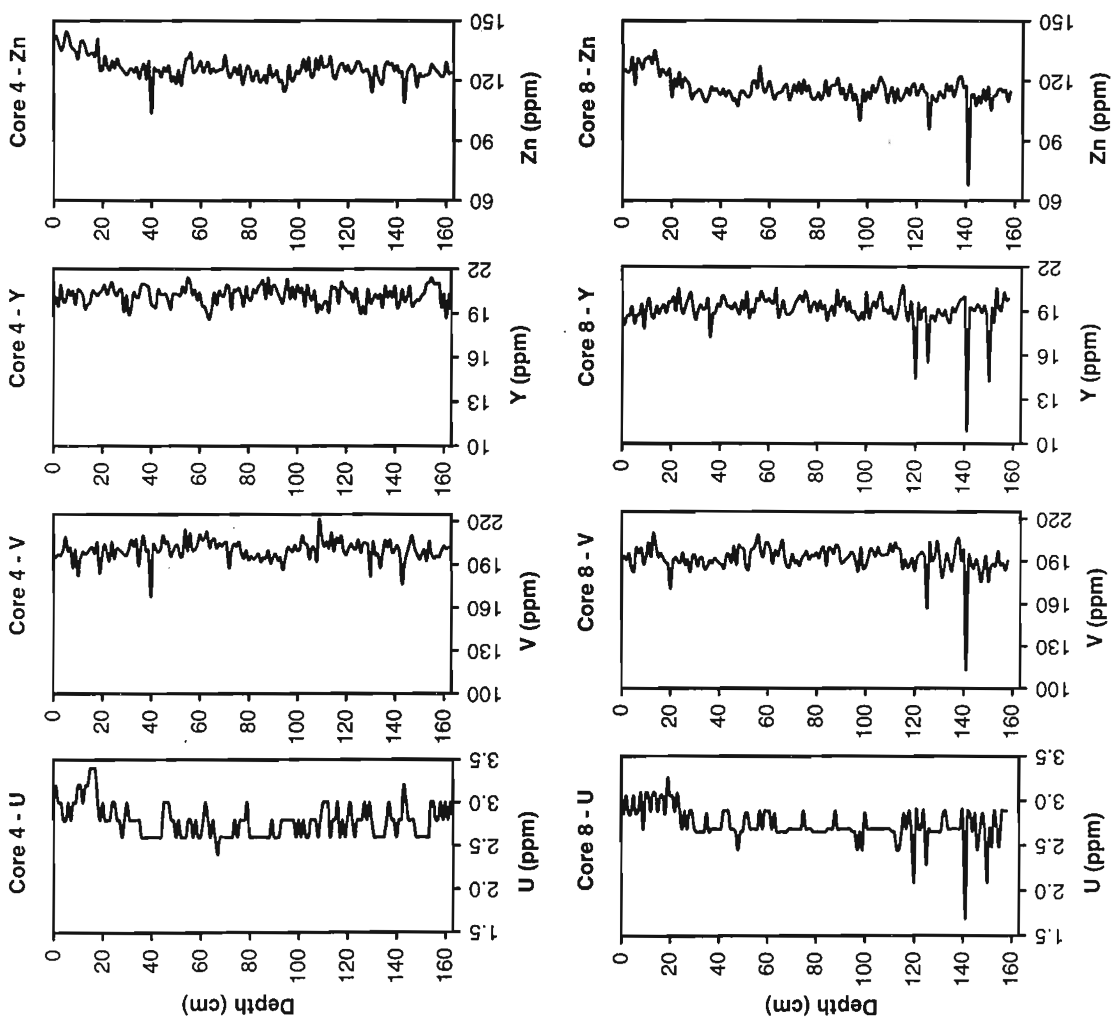

Figure 5 continued

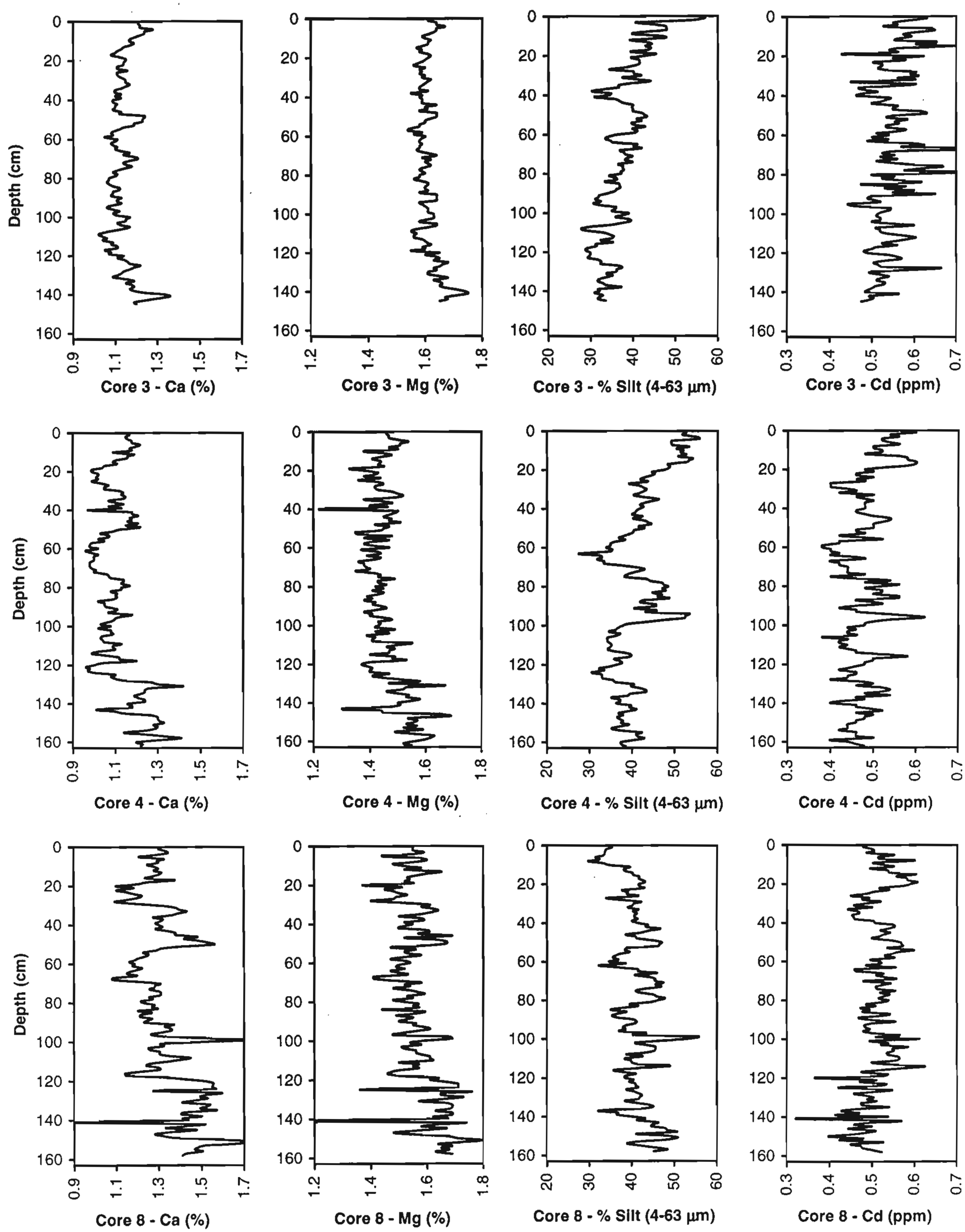

Figure 6. Down-core variations in Ca, Mg, % silt and Cd for Lake Winnipeg 99-900 cores 3, 4 and 8

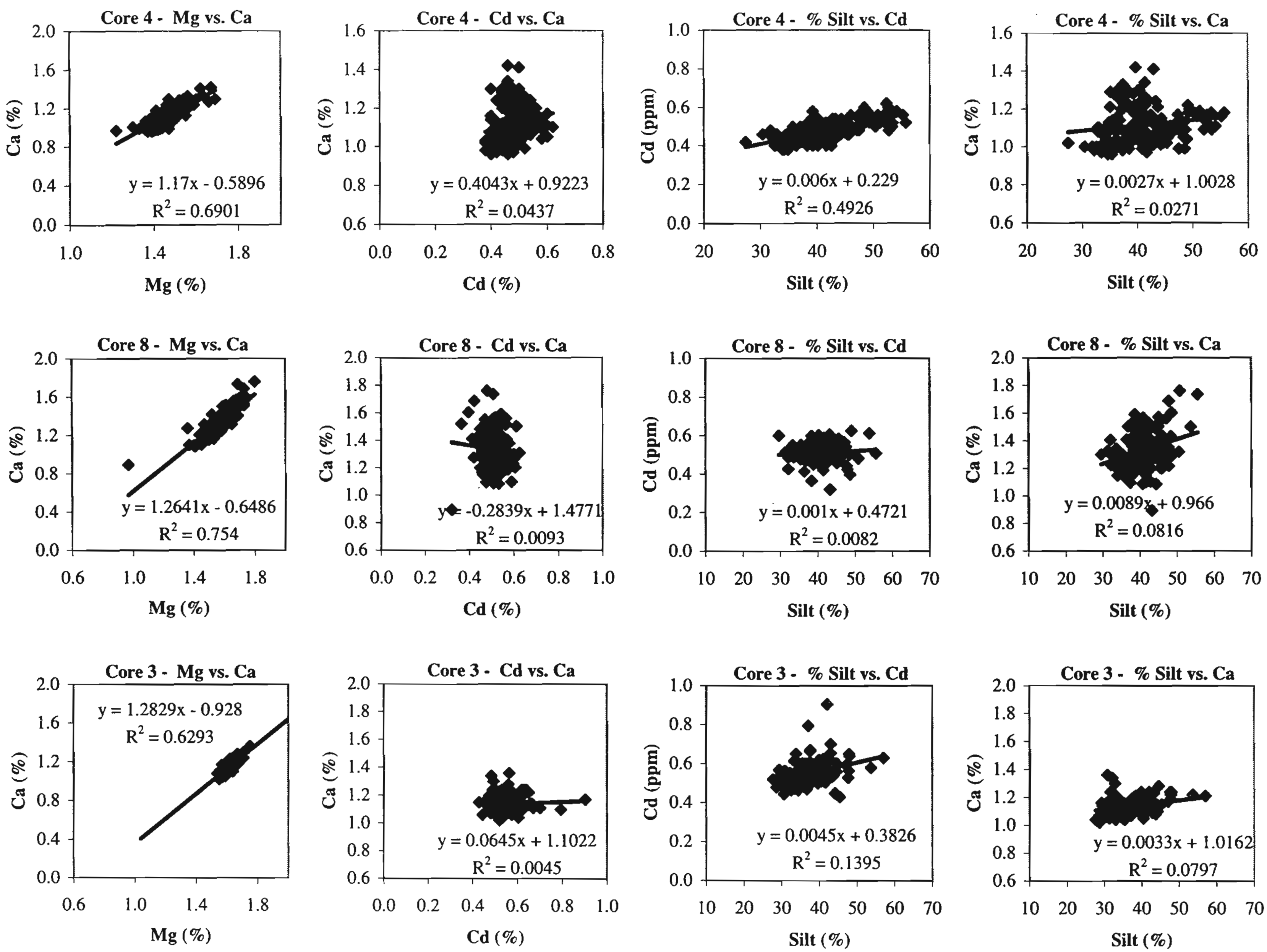

Figure 7. Cross plots of Ca, Mg, Cd and % silt for Lake Winnipeg 99-900 cores 3, 4 and 8

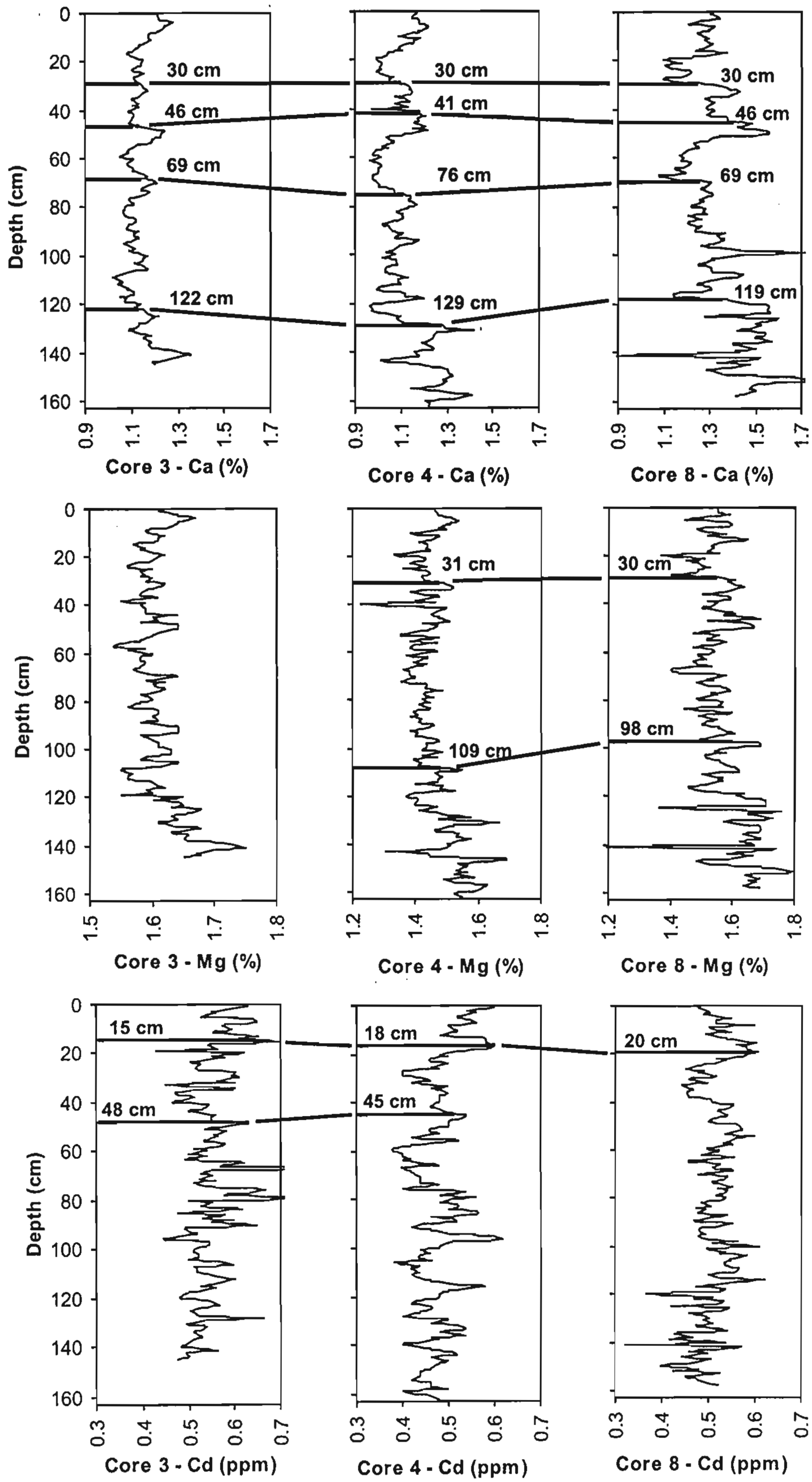

Figure 8. Correlatable inter-core spikes in Ca, Mg and Ca for cores 3, 4 and 8.

5.3 Phosphorus geochemistry of recent sediments in Lake Winnipeg

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ABSTRACT

Following the 1997 Red River flood, research addressing the history and controls on the flood hazard included analysis of sediments in Lake Winnipeg to assess flood history and drainage basin evolution. To do so, 15 gravity cores, each about 1.5 m long, were collected from the south basin during a cruise of the Canadian Coast Guard Ship (CCGS) Namao in August 1999, designated Geological Survey of Canada (GSC) cruise 99-900. The cored sediments were attributed approximately to the past 1100 years on the basis of radiochemistry, paleomagnetic analysis, palynology and radiocarbon dating. Two cores were analyzed for total sediment phosphorus (TP) concentration by ICP-ES as part of a study examining 41 elements. Significant increases in sediment P concentrations were observed in the uppermost 20 cm of the cores and several anomalies in concentration were observed at depth. In order to better interpret the causes of these trends, total phosphorus was re-analyzed by ignition, and forms of phosphorus were determined using sequential extraction. The analysis was augmented using a box core collected in 1994. Three forms of P, non-apatite inorganic P (NAI-P), apatite P (AP), and organic P (OP), were determined. A doubling in TP relative to Al over the last 50 years is largely due to increases in the NAI-P fraction, often associated with anthropogenic sources, suggesting that much of the sedimentary P increase is attributable to changes in the nutrient status of the water column related to anthropogenic inputs. Organic phosphorus exhibits a subtle increase in concentration in the upper 20 cm, likely the result of increases in the primary productivity of the lake. Apatite-P, which is thought to be of detrital origin, remains fairly constant over the length of the cores, although a slight increase with depth, in longer cores, is attributed to the diagenetic formation of this mineral and/or shift in supply of detrital material. Anomalous spikes in P concentration deeper in the cores, comprised mainly of the non-apatite inorganic P fraction, likely result from natural variations in local oxidizing conditions, possibly induced by changes in water circulation.

* Italicized text is repeated in each chapter

INTRODUCTION

The Red River flood of 1997 was a major disaster that drove 103,000 people from their homes. Much is being done, however, to reduce comparable damage and disruption in the future through enhanced dikes and diversions, as well as revised land use and water management practices. The design of these works requires an optimal understanding of the risk. Research therefore has addressed the nature of the largest known flood, in 1826, whether comparable large floods have occurred in recent centuries, and how geomorphic, climatic, land use, and tectonic factors may be changing the flood hazard. These issues are being addressed by examining the geomorphic processes governing evolution of the Red River, archival records of flood history, floodplain stratigraphic records, tree-ring records, changes in valley gradients, and by examining the stratigraphy of Lake Winnipeg sediments (Thorleifson et al., 1998). The coring in Lake Winnipeg, receiving basin of waters from the Red River, was designed to sample sites most likely to have recorded any influx of sediments from the Red River that may have occurred. In addition to recording gradual changes in Red River sediment transport, it was thought that flood events might be recognizable, due to unique properties allowing differentiation from other sediments in the lake, although it was unclear what attribute would best distinguish flood-related sediments. The cores therefore were thoroughly analyzed for chronology, as well as for a broad range of physical, chemical and biological properties to determine which, if any, would record a history of flooding.

Lacustrine sediments are known to be an important sink for many dissolved and suspended substances, including phosphorus (P), hence they provide a record of changes occurring in the lake, whether induced by natural factors or by anthropogenic activities in the watershed. Phosphorus concentrations in sediments, in combination with other geochemical information, are particularly useful for interpreting the nutrient status of the lake over its history (e.g. Yiyong et al., 2001; Massaferro et al., 1999). Simpson and Thorleifson (this volume) documented increases in TP concentrations in the top 20 cm of Lake Winnipeg sediments, as well as occurrences of anomalously high P concentrations in deeper sediments. To determine the origin of these variations, three operationally defined forms of phosphorus were estimated, including non-apatite inorganic phosphorus

(NAI-P), apatite phosphorus (AP) and organic phosphorus (OP), each of which can be interpreted with respect to origin.

LAKE WINNIPEG

Lake Winnipeg, located in central North America, is the eleventh largest lake in the world, having an area of 24,000 km^2 (Hutchinson, 1975). The lake straddles the contact between Paleozoic carbonate rocks to the west and Precambrian igneous and metamorphic rocks of the Canadian Shield to the east. A smaller south basin, approximately 90 km by 40 km, is separated from a north basin, approximately 240 km by 100 km, by a narrow passage known as The Narrows. The glacially-scoured depression in the rocks underlying the lake, with a depth of 50-100 m, is largely filled with fine-grained glacial Lake Agassiz sediments, overlain by up to 15 m of post-glacial Lake Winnipeg sediments (Todd and Lewis, 1996). The bathymetry of the lake is shallow and the bottom is flat, with depths averaging 9 m in the south basin and 16 m in the north basin. The lake has a catchment area extending from the Rocky Mountains to very near Lake Superior, including the basins of the Winnipeg, Saskatchewan, Red, Dauphin and numerous smaller rivers. Outflow from the lake is north to Hudson Bay, through the Nelson River. Post-glacial uplift has caused the north end of the basin to rise relative to the south, causing a gradual rise of lake levels that continues at present (Lewis et al., 2000). The mean annual temperature of the region, recorded at Gimli, is +1.4°C, although the continental climate of the region ranges from hot summers to very cold winters. The mean annual precipitation is 50.8 cm. The lake is ice free from early May to late November (Ice Thickness Climatology, 1992) and ice cover from November to May is consistently thick and continuous. The lake waters are poorly stratified to unstratified and during the summer months water temperatures range from +17°C in the north basin to +19.5°C in the south basin (Todd, 1996), hence bottom sediment temperatures are equally warm in mid-summer. The lake supports a commercial fishery, it is a major destination for recreation, and lake levels are regulated to optimize hydroelectric power generation on the Nelson River.

SAMPLING AND ANALYTICAL METHODS

The sediment cores analyzed for forms of P include two gravity cores (cores 4 and 8) collected on the 99-900 cruise as well as a box core (NAM-7) obtained on the 94-900 cruise (Todd et al., 1996), both from the south basin of Lake Winnipeg (Figure 1).

Ten box cores were collected on a cruise of the CCGS *Namao* in August 1994. The box corer, which consisted of a steel cube with movable base, obtained a half-meter by half-meter by half-meter cubic sample. Following retrieval of the apparatus, the top of the corer apparatus was removed to expose the surface of the sediment. The enclosed sediments were then carefully subsampled using a tube with a diameter of 10 cm and a length of 30-50 cm, with the aid of a vacuum pump to ease the tubes into the sediment without disturbance. Four tubes, approximately 30 cm in length, were obtained from each box core. The cores were extruded using a Teflon plunger, and as sediment emerged from the tube into a clear plastic ring, 1-cm slices were cut off with a stainless steel slicer. The sliced samples were sealed in Whirlpak bags and refrigerated until transfer to the Freshwater Institute (FWI) in Winnipeg for storage at 4°C. Two were used by the FWI, one was sent to the GSC Atlantic core storage facility for archiving, and the other was analyzed by the University of Manitoba (Last, 1996). Prior to analysis, the samples were freeze-dried. NAM-7 was chosen for analysis on the basis of its location in the south basin.

Gravity coring was conducted in calm weather on August 24, 1999 from the CCGS *Namao*. Fifteen gravity cores were obtained using a coring apparatus that consisted of a 100 kg weightstand over a 2 m steel pipe with a 10 cm diameter plastic liner tube. The lengths of cores 4 and 8 were 162 and 158 cm, respectively. The cores were sealed, labeled and transported to Gimli, Manitoba on August 29, where they were refrigerated, and subsequently transported via refrigerated truck to the GSC Atlantic core storage facility in Dartmouth, N.S. A monitoring device attached to the core bundle indicated that the sediments did not exceed a temperature of 19°C at any time during transport. At the University of Rhode Island, the cores were analyzed for physical properties and paleomagnetic chronology, and selected gravity cores were split in half. Later at GSC Atlantic, the entire working half of cores 4 and 8 were sliced into 1-cm sections, packaged in vials and refrigerated. At the FWI, a 1 cc subsample was removed for pollen and textural analysis, and the remaining material was freeze dried and pulverized.

Major and trace element concentrations were measured on 99-900 gravity cores 4 and 8 (Simpson and Thorleifson, this volume) with an inductively coupled plasma emission spectrometer (ICP-ES), following digestion using nitric (HNO_3), hydrofluoric (HF) and perchloric ($HClO_4$) acids. Results for Al were used for determination of phosphorus enrichment and those for Mn were examined with respect to their covariance with TP anomalies deeper in the sediments. TP was also determined by ignition at 550°C and subsequent 16-hour extraction with 1 N HCl. The coefficient of variation of this method, determined from 60 analyses was less than 5 %. Generally, a good agreement was found between the two methods, although TP values determined by ignition were consistently lower than those determined by ICP-ES, probably due to P occluded in lattices of silicate minerals. This form of P is, however, not environmentally significant and the difference is less than 10 %.

NAI-P and AP were determined at selected intervals by a sequential extraction method described by Williams et al. (1976). OP was determined by the difference between the TP and the sum of the NAI-P and AP concentrations (Figure 2). The NAI-P fraction includes orthophosphate adsorbed on Fe and Al-oxides, Fe and Al minerals such as vivianite or variscite, and Ca-P minerals other than crystalline apatite (Williams et al., 1980). NAI-P is generally considered to be a measure of the maximum particulate P that can be rendered soluble during diagenesis. AP includes P bound in crystal lattices of apatite grains and is generally considered biologically inert. This form of P is abundant in detrital particles. OP includes forms of P associated with carbon atoms in C-O-P and C-P bonds.

Chronology for the cores was obtained by Pb-210 and Cs-137 analysis (Wilkinson and Simpson, this volume), paleomagnetic analysis (King et al., this volume), palynology (Anderson, this volume) and radiocarbon dating (Telka, this volume).

RESULTS AND DISCUSSION

Twentieth century trends

TP in NAM-7 exhibits a gradual increase from about 20 cm to the sediment-water interface (Figure 3). This depth, according to Pb-210 chronology, corresponds to the 1930's. More dramatic increases, at about 12 cm, correspond to the 1960's. Similar trends in TP were also observed in the uppermost 20 cm of cores 4 and 8. However, more distinct trends were observed in core 4 and NAM-7 than in core 8. Peak TP concentrations, observed in the lake-bottom sediments were almost 20 % lower in core 8 than those in core 4, perhaps due to local disturbances or deeper mixing of the sediments.

P forms also exhibit trends in concentration with depth (Figure 4). NAI-P, which includes P from mineralized organic matter, increases from 15 cm to the sediment-water interface in NAM-7, suggesting increasing input of readily available P forms. While at a depth of 15 cm the NAI-P comprises about 36 % of the TP, the surficial sediments contain as much as 62 % of the TP in this form. Similar NAI-P trends were observed in the uppermost 20 cm of cores 4 and 8, although the differences in core 8 were less pronounced.

While the NAI-P accounts for as much as 40-45 % of the TP in the surficial sediments in core 4, only 30-35 % of TP is in this P form in surficial sediments of core 8. The proportions and absolute concentrations of various P forms in core 8 were very similar to those observed in suspended sediments from the Red River (Brigham et al., 1996), suggesting that TP concentrations in core 8 may be controlled to a greater extent by the composition of incoming suspended sediment from the Red River.

Within the top 40 cm of cores 4 and 8, OP exhibits minor up-core increases in concentration. However, this trend is not evident in NAM-7. Increases in OP can only be attributed to increases in the proportion of organic matter in the sediments. The increased organic matter contribution may be a result of higher productivity in Lake Winnipeg, resulting from increased nutrient loadings. Some of the sediment OP would be of authigenic origin (derived from the lacustrine organic matter), while some OP would be brought in with the allochtonous organic matter from the watershed. P associated with authigenic organic matter is generally less resistant to diagenetic alteration and would be readily mineralized, hence, determined in the NAI-P fraction. This may explain the relatively uniform profile of OP, with concomitant greater decrease of the NAI-P with depth in core NAM-7. In contrast, OP incorporated in allochtonous (terrestrial) organic matter is more refractory (less easily degraded) and will be determined in the OP fraction. The decreasing OP trend with depth is particularly evident for the longer cores (cores 4 and 8), where the OP concentrations drop from about 200 mg/kg in surficial sediments to half of their values (~100 mg/kg) in the deeper sediments (150 and 146 cm, respectively).

AP, which is largely of detrital origin, shows small up-core decreases in all three cores, likely due to the diagenetic formation of apatite in the deeper sediments. Sediment pore water is generally supersaturated with respect to this mineral because of high concentrations of Ca and PO_4, resulting from dissolution of calcium carbonate and reductive dissolution of iron oxides containing adsorbed orthophosphates (Matisoff et al., 1980; Azcue et al., 1996). Apatite is a thermodynamically stable phase in calcareous sediments and its formation is largely controlled by the reaction kinetics (Matisoff et al., 1980). Stumm and Leckie (1971) have shown that under normal sedimentary conditions, the formation of hydroxylapatite is very slow, hence, this process could be responsible for the observed small down-core increases in AP. Alternatively, a shift in the supply of detrital material may have caused the observed trend. The up-core decrease in apatite P corresponds with an up-core decrease in Mg and Ca in cores 4 and 8 (Simpson and Thorleifson, this volume). Mg and Ca are proxies for carbonate content in the sediments (Henderson and Last, 1998). Henderson and Last (1998) observed up-core decreases in detrital carbonate over the past 4000 years since south basin Lake Winnipeg sedimentation began. Since the shoreline sediments are richer in detrital carbonate material, and the relative contribution of shoreline erosion has been decreasing as transgression of the Lake has progressed over the past 4000 years, the influx of detrital carbonate to the Lake has been gradually decreasing. The proportions of fluvially derived material, as well as autochthonous lacustrine material have, however, increased during this period. This results in lower sedimentation of detrital carbonates and consequently, in situ dissolution of carbonates (Kemp et al., 1976). A similar trend was also observed in Lake Erie sediments (Kemp et al., 1976).

The sediment P enrichment was estimated by calculating an Enrichment Factor (EF). Using this approach, the P concentrations in core NAM-7 were normalized for a conservative element, Al, and compared with corresponding ratios for deeper sediments. This type of procedure was recommended by Kemp and Thomas (1976) to facilitate separation of soil P associated with constant proportions of Al from the excess P derived from anthropogenic sources (Horowitz, 1991; Kemp and Thomas, 1976). This procedure is commonly used to accommodate changes in sediment P concentrations associated with mineralization of organic matter and dissolution of carbonates. The following equation was used in calculation:

$$EF = \frac{TP_x}{TP_{22}} \times \frac{Al_{22}}{Al_x}$$

where: TP_x = Total P concentration at depth x
TP_{22} = Total P concentration at depth 22 cm
Al_x = Al concentration at depth x
Al_{22} = Al concentration at depth 22 cm

A 22 cm horizon was selected as background for this calculation. The values of EF, which represent the degree of concentration increase, are plotted in Figure 5. EF values of ~ 1 indicate no enrichment, whereas EF values > 1 suggest enrichment. A steady increase in EF was observed in the top 20 cm, providing evidence for input of P from anthropogenic activities.

The P enrichment in recent sediments and the observed trends in sedimentary P forms are likely attributable to higher algal productivity, resulting from enhanced P loadings to Lake Winnipeg in recent years. These, in turn, may be attributed to an increase in anthropogenic sources, which coincide with increases in anthropogenic activities in the watershed. A lack of P increase in recent sediments of non-impacted basins supports this concept. Anthropogenic sources of nutrients include fertilizers and animal wastes from agricultural activities, sewage treatment plant effluents from urban centers, and industrial effluents. Fertilizer usage in Canada has increased significantly since the 1960s, although most of this increase is from nitrogen fertilizers in the Prairie region. According to Statistics Canada, there was a steady, approximately 4.5-fold increase in fertilizer usage in Manitoba, and a nearly 3-fold increase in fertilizer P input between 1967 and 1993 (Figure 6). Excessive loading of nutrients from fertilizers contributes to other external loadings, which stimulate the algal growth and can lead to deterioration of the lake's trophic condition.

Pre-twentieth century trends

In cores 4 and 8, OP concentrations remain constant with depth, but increase moderately (50-100 mg/kg) from depth of approximately 20 cm. Increases occurring at the time of the onset of intense agriculture suggest that increases in OP could be the result of anthropogenic activity rather than a natural gradual shift in organic matter supply to the lake.

In addition to trends in lake-bottom P concentrations, noticeable peaks in TP were observed with depth in the two cores with longer records (Figure 7). However, while three prominent peaks in TP concentrations were observed in the deeper sediments of core 4 (60, 95 and 121 cm), similar P maxima were noticeably absent from the deeper sediments of core 8. According to the chronology model (Wilkinson and Simpson, this volume), the peaks correspond to approximate ages of 1650 A.D., 1400 A.D. and 1225 A.D., respectively. These peaks are dominantly comprised of increases in the NAI-P form, with little change in the concentrations of OP and AP forms (Figure 8). The P-rich peaks in the lower part of core 4 are also enriched in Mn (Figure 9) (Simpson and Thorleifson, this volume), suggesting that the layers were formed under strongly oxidizing conditions, marking an intense episode of mineral precipitation. The precipitated P would increase both the absolute NAI-P concentrations in these layers and the relative contribution of this P form to the TP content. The strong association of NAI-P with Mn suggests that similar processes controlled the precipitation of both. The conditions controlling formation of these layers were likely localized, as the layers are not present at the same depths in cores 4 and 8. Similar P enrichment concomitant with increases in Mn concentrations was observed in Lake Ontario sediments west of the mouth of Niagara River (Manning and Mayer, 1987). It was suggested that the formation of these layers was related to the current flow pattern. A comparable cause may be responsible for the layers of enhanced P and Mn concentrations in Lake Winnipeg.

Chronological data reveal small differences in the sedimentation rates between the two sites. The estimated sedimentation rates in core 4 are slightly higher than those in core 8. Because of the relatively low sedimentation rates in both cores, mixing of sediments is an important process affecting the distribution of particles and associated contaminants (Robins, 1982), including phosphorus, upon their deposition. Sediment P profiles reveal a greater depth of the surficial mixed layer (12-13 cm) in core 8 than in core 4 (~ 6 cm), suggesting higher ratios of mixing rates to sedimentation rates in core 8 than those in core 4. The higher rates of mixing would more effectively smooth out short-term variations over the mixed layer. This, together with the lower P concentrations observed in core 8 may have caused attenuation of P and Mn peaks.

The trend of increasing AP concentrations with depth in cores 4 and 8 continues over the length of these cores (Figure 8) and, as previously discussed is likely the result of the authigenic apatite P formation and/or shifts in the supply of detrital material. In total, approximately a 10 % difference is observed between the AP concentrations of lake-bottom and deep sediments.

CONCLUSIONS

- The phosphorus profiles show a steady increase in TP and NAI-P concentrations and a subtle increase in OP concentrations in the uppermost 20 cm of the sediments, while AP concentrations remain relatively constant over this interval.

- Increases in NAI-P suggest that these TP increases are the result of anthropogenic activities in the watershed. Concentrations increase dramatically in sediments at depths corresponding to the 1960's, perhaps due to increased usage of fertilizers in the Prairies and the resulting enhanced nutrient loading to the Lake.

- Based on calculation of an enrichment factor relative to a conservative element, the uppermost sediments are enriched in P by a factor of up to 2 relative to background levels, supporting the presence of anthropogenic sources of P.

- Increases in OP in recent sediments are likely due to increases in the Lake's primary productivity, probably related to the anthropogenic influx of nutrients.

- The subtle increase of AP in deeper sediments may be attributable to a shift in the supply of detrital carbonate or to the diagenetic formation of apatite.

- Three prominent peaks in TP concentrations observed in the deeper sediments of core 4 (60, 95 and 121 cm), but absent from core 8 are likely the result of mineral formation under oxidizing conditions, as indicated by their association with peaks in Mn concentrations. The presence of such layers in only one of the cores suggests that the phenomenon is localized.

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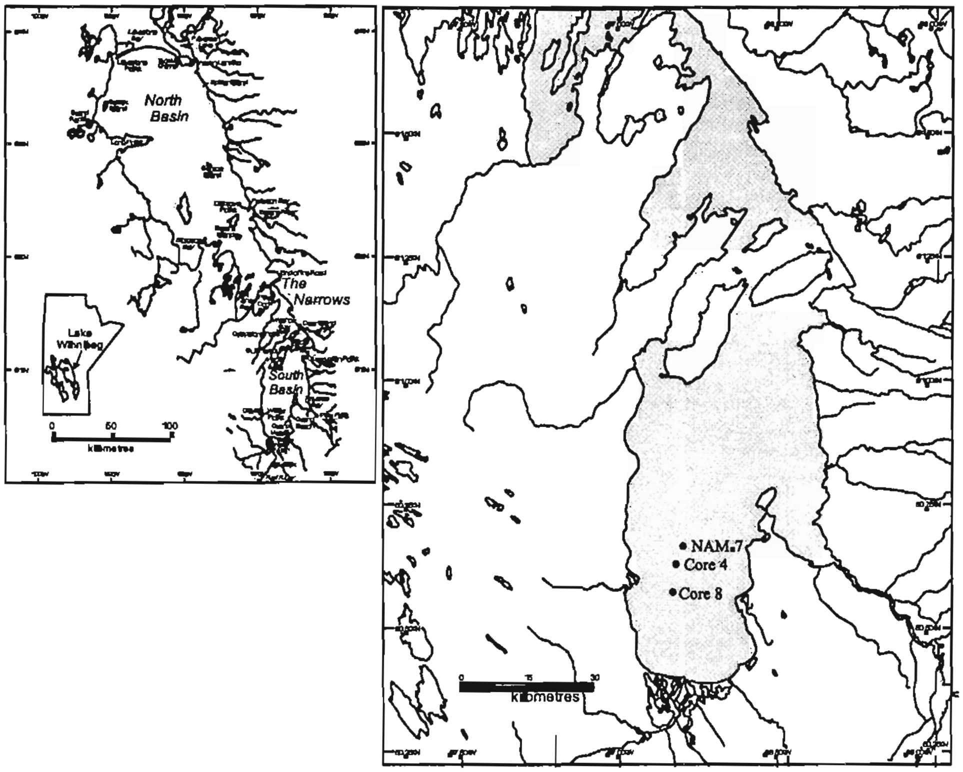

Figure 1. Lake Winnipeg coring sites

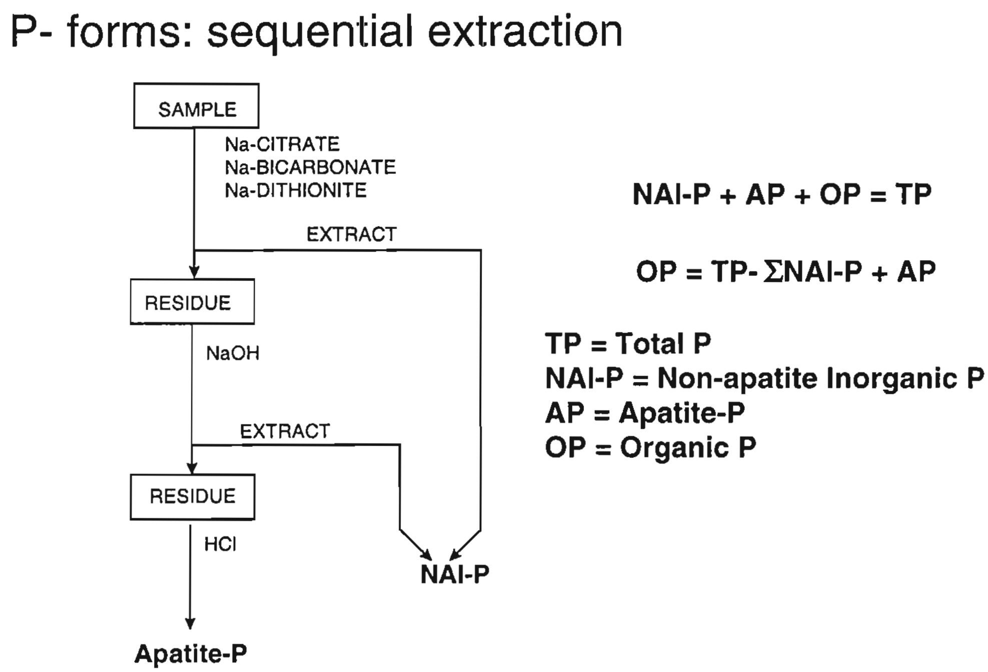

Figure 2. Schematic outline of analytical procedures used to determine P forms in sediments

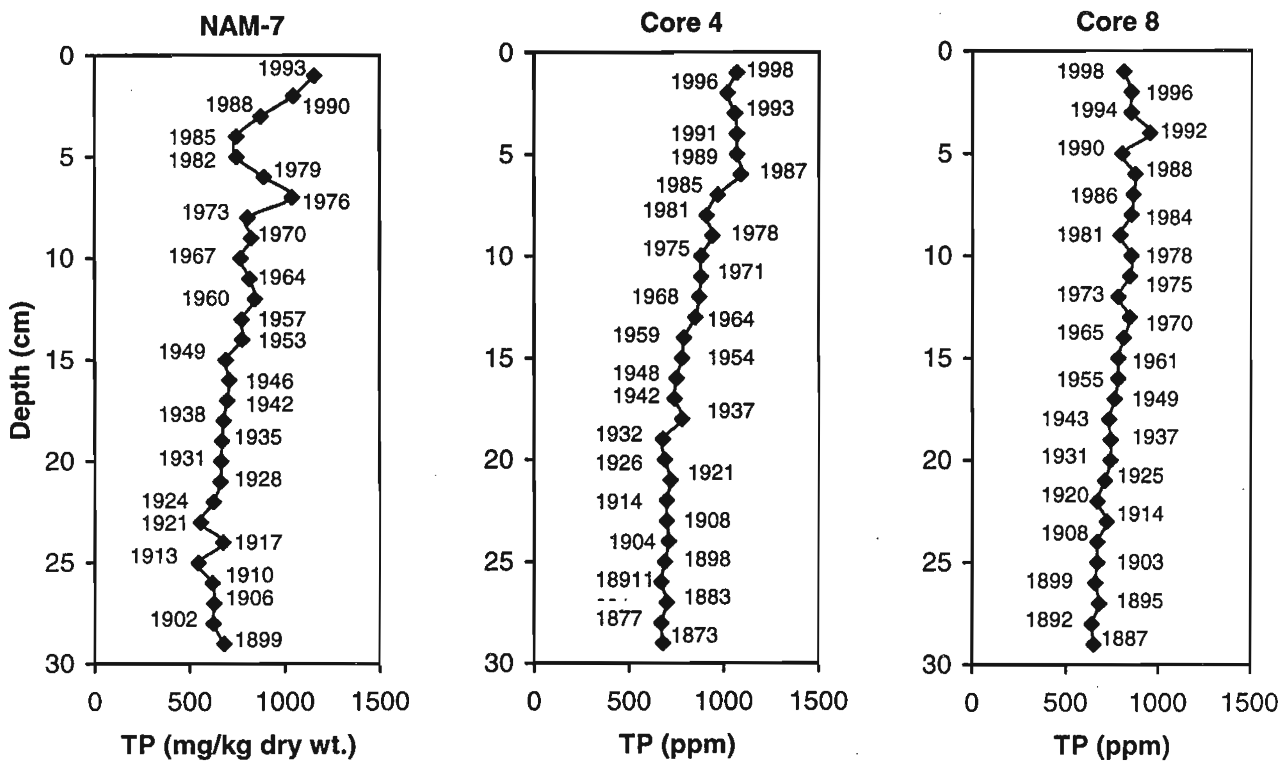

Figure 3. TP in uppermost 30 cm of NAM-7, core 4 and core 8. TP determined by ignition for NAM-7 and by ICP-ES for cores 4 and 8.

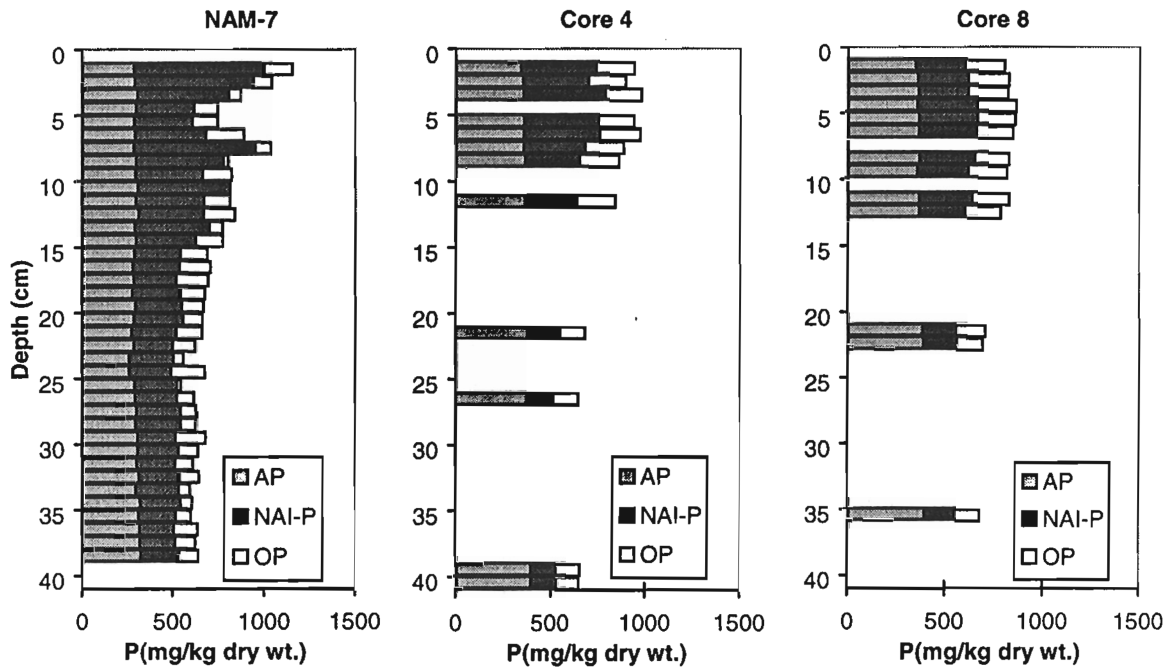

Figure 4. Phosphorus forms in uppermost 40 cm of NAM-7, core 4 and core 8. Determinations made using sequential extraction.

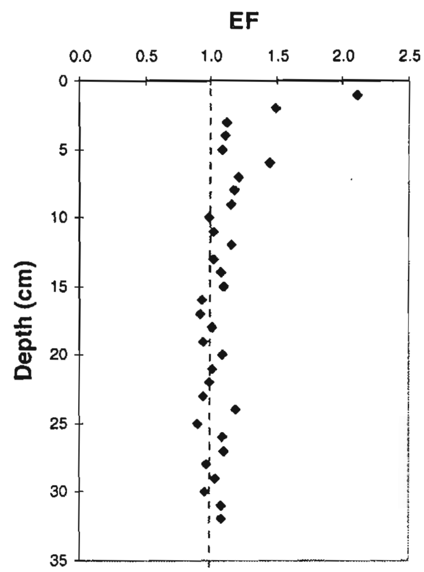

Figure 5. Phosphorus Enrichment Factor in NAM-7

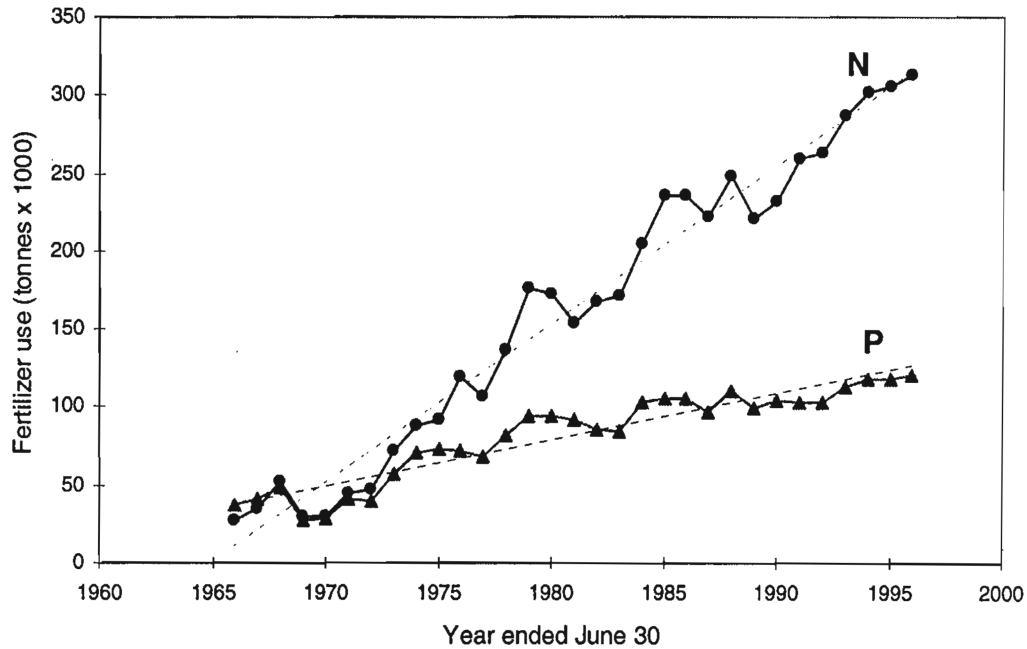

Figure 6. Nitrogen and phosphorus fertilizer usage in Manitoba in 1966-1996

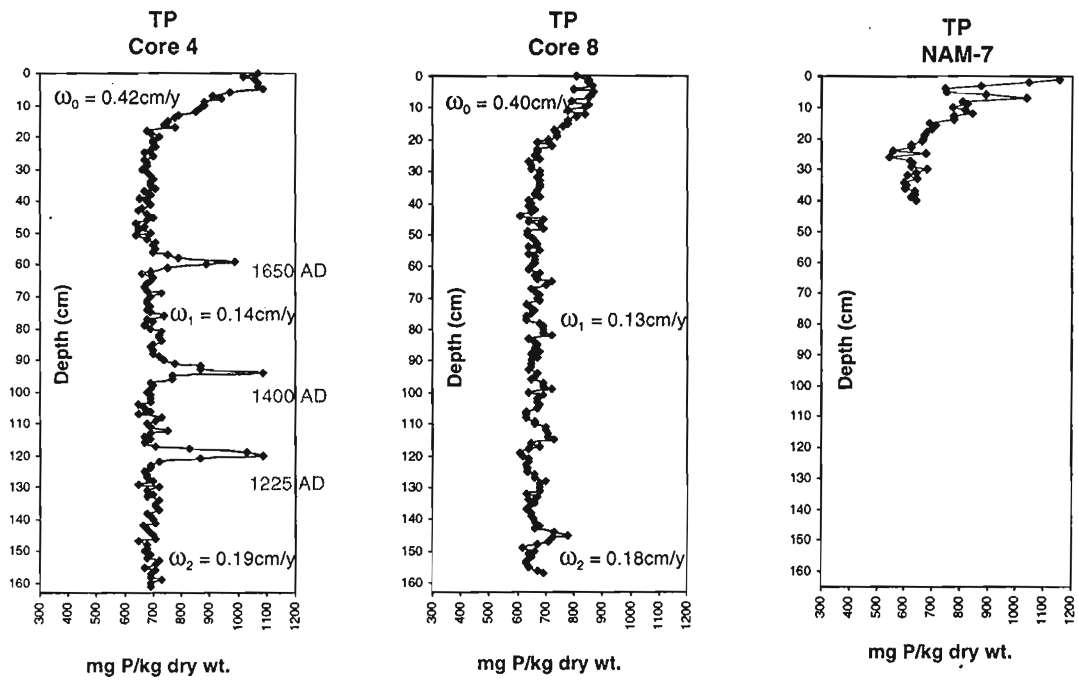

Figure 7. TP profiles for cores 4 and 8. For comparison, profile of NAM-7 is included. Concentrations for cores 4 and 8 determined by ICP-ES and for NAM-7 by ignition.

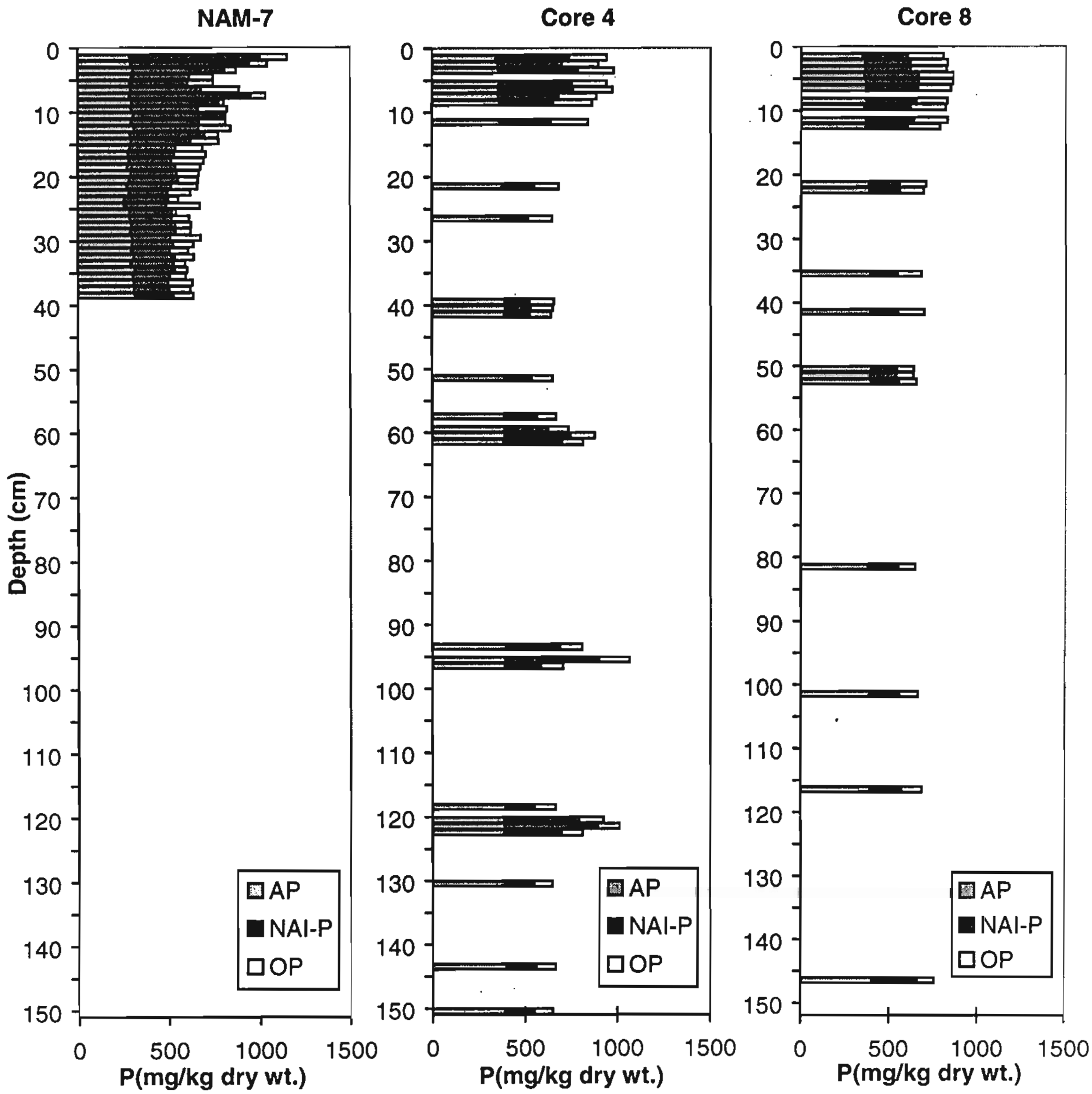

Figure 8. Phosphorus forms in NAM-7, core 4 and core 8. Determinations made using sequential extraction.

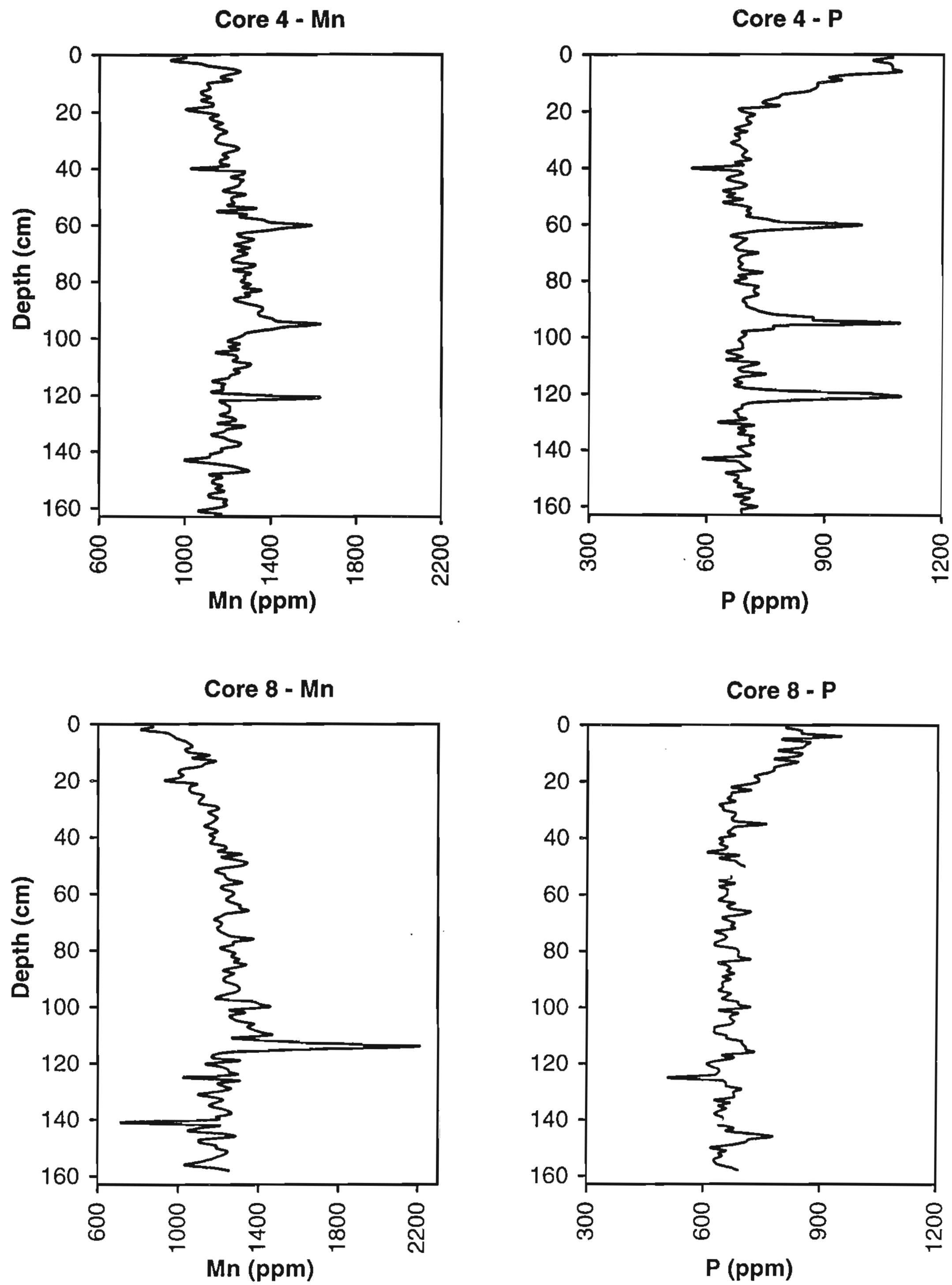

Figure 9. Down-core variations in Mn and Total P in cores 4 and 8. Determinations made by ICP-ES.

5.4 Rock-Eval organic analysis of Lake Winnipeg 99-900 cores 4 and 8

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ABSTRACT

Following the 1997 Red River flood, research addressing the history and controls on the flood hazard included analysis of sediments in Lake Winnipeg to assess flood history and drainage basin evolution. To do so, 15 cores, each about 1.5 m long, were collected from the south basin during a cruise of the Canadian Coast Guard Ship (CCGS) Namao in August 1999, designated Geological Survey of Canada (GSC) cruise 99-900. Rock-Eval analysis, a means for determining the forms of organic material, of cores 4 and 8 was completed, primarily to test for influxes of terrestrial organic material during floods. The cored sediments are attributed approximately to the past 1100 years on the basis of radiochemistry, paleomagnetic analysis, palynology and radiocarbon dating. The results, in particular hydrogen and oxygen indices, implied that most of the lacustrine organic matter (OM) was either derived from terrestrial sources, or was significantly altered by diagenesis. With the aid of additional information from carbon and nitrogen elemental and carbon isotopic analyses, it appears most likely that the lacustrine OM was primarily derived from aquatic sources, but has undergone alteration. Lack of a corresponding down-core decrease indicates that the majority of the OM alteration occurred in the water column under oxidizing conditions, prior to deposition. Diagenetic alteration likely continued after deposition at a slower rate. Large shifts in Rock-Eval properties in the top 22 cm of the cores have likely resulted from a combination of processes, including increases in sedimentation rate, changes in productivity, and the time required for OM to degrade to background levels. Co-variant increases of metals with total organic carbon could be coincidental or the result of biological recycling of metals in the upper 20 cm of the lake-bottom sediments. Anomalies readily attributable to floods were not observed, either indicating that the terrestrial OM is indistinguishable from the altered lacustrine OM, or because any influx of terrestrial organic matter that occurs during a flood is insignificant relative to background accumulation of lacustrine organic matter.

INTRODUCTION

The Red River flood of 1997 was a major disaster that drove 103,000 people from their homes. Much is being done, however, to reduce comparable damage and disruption in the future through enhanced dikes and diversions, as well as revised land use and water management practices. The design of these works requires an optimal understanding of the risk. Research therefore has addressed the nature of the largest known flood, in 1826, whether comparable large floods have occurred in recent centuries, and how geomorphic, climatic, land use, and tectonic factors may be changing the flood hazard. These issues are being addressed by examining the geomorphic processes governing evolution of the Red River, archival records of flood history, floodplain stratigraphic records, tree-ring records, changes in valley gradients, and by examining the stratigraphy of Lake Winnipeg sediments (Thorleifson et al., 1998). The coring in Lake Winnipeg, receiving basin of waters from the Red River, was designed to sample sites most likely to have recorded any influx of sediments from the Red River that may have occurred. In addition to recording gradual changes in Red River sediment transport, it was thought that flood events might be recognizable, due to unique properties allowing differentiation from other sediments in the lake, although it was unclear what attribute would best distinguish flood-related sediments. The cores therefore were thoroughly analyzed for chronology, as well as for a broad range of physical, chemical and biological properties to determine which, if any, would record a history of flooding.

In order to examine properties of the sediment organic matter (OM), the cores were analyzed by Rock-Eval pyrolysis. The Rock-Eval method was initially developed for use in the petroleum industry to evaluate the hydrocarbon potential of petroleum source rocks by providing estimates of (1) the type of OM, (2) the extent of thermal evolution (thermal maturity), and (3) the quantity of OM in a sample (Espitalié et al., 1985). These properties indicate the current status of a given sample with respect to petroleum generation and expulsion. Organic matter ranges from inert material like charcoal, with no petroleum generation potential, through coal or coaly material, with only the potential to expel gas, to organic matter dominated by hydrogen-rich lipids commonly associated with marine or lacustrine algae, which tend to yield significant quantities of oil and gas. Thermal maturity ranges from completely unaltered organic material to metamorphic rock in which only graphitic or dispersed carbon is residual. Quantities of organic carbon range from virtually zero to about 75 % in essentially pure organic matter.

While most Rock-Eval analyses have been carried out on sedimentary rocks in search of petroleum generation potential, the technique has also been used extensively to

* Italicized text is repeated in each chapter

document properties of sediments recovered in Ocean Drilling Program coring (Peters and Simoneit, 1982). Recently, Rock-Eval techniques have been applied to the analysis of organic matter in lacustrine sediments, and can be used to gain insight into paleoenvironments, including climate change and anthropogenic effects (Meyers and Lallier-Vergès, 1999).

It was thought that Rock-Eval analysis, including calculation of Total Organic Carbon (TOC), the Hydrogen Index (HI) and the Oxygen Index (OI, also known as OICO2) of Lake Winnipeg sediments might provide information on the type and proportion of allogenic versus authigenic organic matter in the lake over time, including possible recognition of flood events. Specifically, it was thought that Rock-Eval analysis might preserve a record of the rapid influx and deposition of higher land plant debris that might be expected to accompany floods. In addition, it became apparent that an understanding of algae in the lake is an important indicator of eutrophication. Rock-Eval analysis may also provide information on the preservation of organic matter in the lake, and hence, information on preservation controls, including sedimentation rate, particle grain size, the degree and timing of biological recycling of organic matter and bottom water-oxygen conditions.

LAKE WINNIPEG

Lake Winnipeg, located in central North America, is the eleventh largest lake in the world, having an area of 24,000 km^2 (Hutchinson, 1975). The lake straddles the contact between Paleozoic carbonate rocks to the west and Precambrian igneous and metamorphic rocks of the Canadian Shield to the east. A smaller south basin, approximately 90 km by 40 km, is separated from a north basin, approximately 240 km by 100 km, by a narrow passage known as The Narrows. The glacially-scoured depression in the rocks underlying the lake, with a depth of 50-100 m, is largely filled with fine-grained glacial Lake Agassiz sediments, overlain by up to 15 m of post-glacial Lake Winnipeg sediments (Todd and Lewis, 1996). The bathymetry of the lake is shallow and the bottom is flat, with depths averaging 9 m in the south basin and 16 m in the north basin. The lake has a catchment area extending from the Rocky Mountains to very near Lake Superior, including the basins of the Winnipeg, Saskatchewan, Red, Dauphin and numerous smaller rivers. Outflow from the lake is north to Hudson Bay, through the Nelson River. Post-glacial uplift has caused the north end of the basin to rise relative to the south, causing a gradual rise of lake levels that continues at present (Lewis et al., 2000). The mean annual temperature of the region, recorded at Gimli, is +1.4°C, although the continental climate of the region ranges from hot summers to very cold winters. The mean annual precipitation is 50.8 cm. The lake is ice free from early May to late November (Ice Thickness Climatology, 1992) and ice cover from November to May is consistently thick and continuous. The lake waters are poorly stratified to unstratified and during the summer months water temperatures range from +17°C in the north basin to +19.5°C in the south basin (Todd, 1996), hence bottom sediment temperatures are equally warm in mid-summer. The lake supports a commercial fishery, it is a major destination for recreation, and lake levels are regulated to optimize hydroelectric power generation on the Nelson River.

SAMPLING AND ANALYTICAL METHODS

Selection of five sampling sites in the south basin of Lake Winnipeg was based on proximity to the Red River mouth and on the absence of ice scour on sidescan sonar records previously obtained in 1994 on the 94-900 Namao cruise (Lewis et al., this volume) (Figure 1). Site 5 was the southernmost point on the north-south survey line that lacked ice scour. Sampling was conducted in calm weather on August 24, 1999 from the CCGS Namao. Three cores were obtained at each of the five sites using a gravity corer consisting of a 100 kg weightstand over a 2 m steel pipe with a 10 cm diameter plastic liner tube. The length of the cores ranged from 107 cm to 170 cm. The cores were sealed, labelled and transported to Gimli, Manitoba on August 29, where they were refrigerated, and subsequently transported via refrigerated truck to the GSC Atlantic core storage facility in Dartmouth, N.S. A monitoring device attached to the core bundle indicated that the sediments did not exceed a temperature of 19°C at any time during transport. Paleomagnetic and physical property data, determined at the laboratory of Professor J.W. King at the University of Rhode Island, provided information used to select cores that would be representative of the offshore sediments (King et al., this volume). Paleomagnetic profiles indicated more rapid accumulation of sediments at the more northerly sites and hence a higher resolution for examining environmental change. Based on these observations, core 8 (site 3), core 4 (site 2) and core 3 (site 1) were selected as the primary records for detailed study.

A total of 162 and 158 samples from cores 4 and 8, respectively, were sampled at 1-cm increments at GSC Atlantic facilities in Dartmouth. The samples were freeze-dried and pulverized at the Freshwater Institute in Winnipeg and 100 mg aliquots obtained at GSC Calgary labs after the samples had been processed elsewhere for elemental analysis.

The sediments were analyzed on a Vinci Technologies Rock-Eval 6 instrument at GSC Calgary (Lafargue, 2001; Behar et al., 2001; Peters, 1986). Rock-Eval analysis comprises two steps: pyrolysis and oxidation. Pyrolysis involves progressive heating in the absence of air in order to determine the amounts of hydrocarbons released during progressive temperature steps. Immediately following pyrolysis, the residual material is transferred to a second oven where it undergoes combustion (oxidation) by heating to 850°C in artificial air (N_2/O_2; 80/20). During both steps, the microprocessor-controlled temperature rises and volatiles are released from the sediment samples into a stream of inert gas (nitrogen). The amount of hydrocarbon is measured by a flame ionization detector (FID), while the amount of CO_2 is determined by an infra-red (IR) detector. The pyrolysis and combustion steps of two successive samples are analyzed concurrently and each sample requires 36 minutes for analysis, with the exception of the first and last sample, which require longer. The samples were analyzed continuously in scrambled order, with only a few sporadic breaks for reloading of samples and analysis of priority samples.

Twelve parameters were measured (Table 1) by the Rock-Eval 6 apparatus, while others were calculated from the measured parameters (Table 2). Measured and calculated parameters were automatically determined by the Rock-Eval software, however, calculated parameters may also be calculated from formulas (Table 2). Most of the literature is based on Rock-Eval II technology, the precursor to Rock-Eval 6 technology and some of the terminology varies slightly between the two.

Of the measured Rock-Eval 6 parameters, S1, S2, S3CO2, S3CO, S4CO2 and S4CO are used for determination of commonly calculated parameters. S1, S2, S3CO2 and S3CO are determined during the pyrolysis step, while S4CO2 and S4CO are determined during the oxidation step. S1 and S2 are the amounts of hydrocarbons released during heating at 300°C and during ramped heating (25°C/minute) from 300°C to 650°C, respectively. S3CO2 and S3CO are the amounts of carbon dioxide (CO_2) and carbon monoxide (CO), respectively, released from the organic matter during pyrolysis. S4CO2 and S4CO are the amounts of carbon dioxide and carbon monoxide, respectively, released from the organic matter during oxidation. Of the calculated parameters, the Total Organic Carbon (TOC), the Hydrogen Index (HI) and the Oxygen Index (OI) are the most commonly used for determination of paleoenvironmental information (Table 2). The TOC in the sediments is the sum of pyrolysed and residual organic carbon. HI is a proxy for the atomic H/C ratio of the organic matter and OI is a proxy for the atomic O/C ratio (Espitalié et al., 1977). Analytical precision and accuracy were monitored through the analysis of duplicates and laboratory standards, respectively. Duplicate samples were analyzed, on average, every 13 samples and standards every 11 samples.

RESULTS

Corrected Rock-Eval 6 results for cores 4 and 8 are presented in Tables 3 and 4, respectively. A correction was applied to S3CO2 and S3CO results (measured parameters) for core 4, to remove an analytical trend that was indicated by the standards and was sufficiently large to mask natural trends in the data set. All other measured parameters for both cores were found to have insignificant trends. Re-ordering of samples in a semi-random fashion prior to laboratory analysis facilitated confirmation of the trend indicated by the standards. The linear trends were removed by linear regression and subtraction of the trend while maintaining the mean value of the data set. The top 25 cm of sediment were excluded from this procedure to avoid influencing the slope of the trend lines with a trend associated with this interval of the cores. Following detrending of measured parameters, the calculated parameters were recalculated using the corrected S3CO2 and S3CO values.

Data tables include the depth in cm below the top of the core and the values obtained for each of the measured and calculated Rock-Eval parameters (Tables 3 and 4). Down-core variations in all Rock-Eval parameters for cores 4 and 8 are shown in Figures 2 and 3, respectively, with the exception of Qty, S'2 and KFID, which are primarily used as analytical checks and show no variation with depth, and of S5bCO2, for which zero values were obtained. Cross plots of elemental concentrations versus TOC as well as S1 and S2 values versus TOC are shown in Figures 4 and 5.

Quality assurance and quality control

Results of duplicate analyses and analytical precision for each parameter in cores 4 and 8 are shown in Tables 5 and 6, respectively. For both cores, a precision of less than 10 % RSD (relative standard deviation) was attained for all parameters, with the exception of S1, S4CO, PI and RCCO. Poor precision for measured parameters (S1, S4CO) was likely the result of the small amounts of hydrocarbon and carbon monoxide released during defined temperature ranges, while poor precision for calculated parameters (PI and RCCO) was a function of poor precision in measured values.

The results for an internal standard (standard 9107) are shown in Tables 7, 8 and 9. This material does not have a certified value, so strictly speaking, accuracy cannot be calculated. However, it was analyzed multiple times throughout each laboratory run and the results compared with previous values to verify that the instrument was functioning in a reproducible manner. Throughout analysis of cores 4 and 8, the mean remained constant and the standard deviations low (< 5), indicating consistent laboratory conditions and good reproducibility. Results were also obtained for an external standard, standard TCA8010 (Table 9). Results for this standard were not consistent and standard deviations were quite high (> 30) for some parameters (HI, OICO2, OICO and OIRE6), perhaps due to the very low organic content of this mineral soil that had been inserted to monitor the preceding elemental analyses.

Variations in Rock-Eval parameters with depth

The observed variations in Rock-Eval parameters with depth follow one of three main trend types (Figures 2 and 3). The first, and most commonly observed trend, consists of a fluctuation around a near-constant mean for the lower 140 cm with an abrupt to gradual increase in the top 22 cm (150 to 400 % increase in S1, S2, S3CO2, S3CO, S4CO2, S4CO, S2/S3, PC, RCCO2, RCCO, RC, TOC and HI). A second type of trend observed consists of a fluctuation around a near-constant mean for the lower 140 cm with an abrupt or gradual decrease in the top 22 cm (110 % average increase in OICO2 and OIRE6). A third category shows no trend, as there is a high degree of background scatter for these parameters (Tpeak, Tmax, PI and OICO). A unique pattern of increases and decreases with depth is exhibited for S5bCO2, particularly for core 4.

An additional trend was observed for S3CO2, OICO2 and OIRE6 in core 8. At a depth of 120 cm there is an abrupt shift from lower values to higher values (about a 10 % increase). These trends are almost imperceptible in core 4, due to a higher degree of background scatter attributable to the poorer precision obtained for core 4 results.

Rock-Eval and elemental cross correlation

Cross plots were used to determine if elemental concentrations and Rock-Eval parameters co-varied with TOC (Figures 4 and 5). Only cross plots that showed co-variance between parameters are illustrated. Mercury and lead exhibit a convincing linear co-variance with TOC for both cores (R^2 values > 0.55), while cadmium, uranium and zinc exhibit a weaker co-variance with TOC. Phosphorus-TOC cross plots exhibit two populations, one positively associated with TOC and the other independent of TOC. S1 and S2 exhibit a strong non-linear co-variance with TOC for both cores (R^2 values > 0.9).

DISCUSSION

Lacustrine organic matter

The lacustrine organic matter of most lakes is derived dominantly from plant detritus, with only a small proportion derived from animal material (Meyers and Lallier-Vergès, 1999). Plant material can be classed as nonvascular, containing little or no carbon-rich cellulose, or vascular, containing a large proportion of cellulose. Non-vascular plants include phytoplankton, which are aquatic, while vascular plants include trees, shrubs and grasses, which are most commonly terrestrial, although some are suited to shallow water. The relative proportion of authigenic versus allogenic organic matter is of interest, as this ratio is controlled by lake morphology, watershed topography, climatic conditions and the productivity of the plants (Meyers and Lallier-Vergès, 1999).

A number of processes, occurring both prior to and after sedimentation, affect the preservation of organic matter in lacustrine environments. In fact, up to 60-70 % of the organic matter in young lacustrine sediments consists of humic material, which is derived from diagenetic processes, in particular, microbial reworking (Ishiwatari, 1985). In addition, significant proportions of organic matter may be lost during transport and deposition. Thus, the composition of lacustrine organic matter, indicated by Rock-Eval analysis apparently will likely be determined by the type and amount of the source organic matter and the degree of diagenetic alteration (Meyers and Lallier-Vergès, 1999).

Rock-Eval signatures of primary (source) organic matter

The Rock-Eval parameters TOC, OI and HI are commonly employed for determining organic matter sources. Higher TOC and HI values are indicative of enhanced algal productivity, which may be a signal of eutrophication, while low HI values are indicative of enhanced terrestrial input to the lake (Meyers and Lallier-Vergès, 1999). For organic matter of terrestrial origin, the TOC is variable, depending on land surface conditions. Studies have also shown that variations in HI may be useful in distinguishing between periods of cyanobacteria (blue-green algae) versus diatom dominance in lake waters (Ariztegui et al., 2001). Ariztegui et al. showed that lower HI values correspond with periods of higher diatom productivity and lower cyanobacteria productivity.

A common tool for classification of organic matter type is the van Krevelen plot of atomic H/C versus O/C, which differentiates the type and thermal maturity of kerogen (Tissot et al., 1974). Hydrogen and oxygen indices are commonly plotted against one another, approximating the van Krevelen plot (Espitalié et al., 1977). Three main fields of organic matter are identified, including Type I organic matter, typical of microbial biomass or the waxy coatings of land plants, Type II organic matter, derived from algae, and type III organic matter, typical of woody plant material (vascular plants).

Effects of organic matter alteration on Rock-Eval signatures

Processes of alteration of organic matter have been discussed by Meyers and Ishiwatari (1993), who found that alteration can occur any time between its synthesis and burial, including processes in the water column, those at the sediment-water interface and those at greater depth. They indicated that within the water column, the most prevalent form of organic matter alteration is biochemical oxidation of organic matter, accomplished by microbes, which recycle (mineralize) the most easily degraded forms of organic matter. Terrestrial organic matter was found to be less easily degraded by microbes (more refractory) and, as a result, has a higher preservation potential. Conversely, algal organic matter was found to be more easily recycled by microbes, and subsequently has a lower preservation potential. Eadie et al. (1984), for example, showed that 94 % of the primary aquatic organic matter in Lake Michigan is recycled before reaching the lake bottom. This effect might be less pronounced in a shallower lake such as Lake Winnipeg, as the settling time of particles would be reduced. Similarly, higher sedimentation rates and less oxygenated waters would enhance preservation of organic matter (Meyers and Ishiwatari, 1993).

Organic matter that has reached the lake bottom is further subjected to alteration during re-suspension and bioturbation of the sediments, prolonging exposure of the organic matter to oxidation. Alteration of organic matter below the zone of bioturbation occurs at a much slower rate by microbes that tolerate anoxic conditions.

Organic matter that has been exposed to oxidizing conditions, and hence alteration, during transport, deposition and burial, generally has high Tmax values and low S2 values (Peters, 1986). Oxidation causes HI values to decrease and OI values to increase (Durand and Monin, 1980), thus shifting the Rock-Eval signature of the organic matter towards Type III classification. Thus, a Type III classification could be interpreted as organic matter highly altered by diagenesis under oxiding conditions. Non-oxidative degradation of organic matter may be evidenced by decreases in TOC and HI, and increases in OI (Meyers and Lallièr-Verges, 1999; Patience et al., 1995).

INTERPRETATION

Sources and quantity of organic matter in Lake Winnipeg sediments

The Rock-Eval results from Lake Winnipeg sediments have values that typically would imply most of the organic matter is derived from vascular terrestrial plants. This is indicated by the very low HI values and the position of the sediments in the Type III OM field on the pseudo-van Krevelen diagram (Figures 2, 3 and 6). The change in Rock-Eval parameters (most importantly TOC, HI and OI) in the top 22 cm of the cores could be explained by a change in the type and/or amount of organic matter from primary sources. The increase in TOC from about 1 % to about 2 % at the top of the cores could be explained by an increase in sedimentation rate, caused by land use changes, or it could represent an increase in the productivity of plants, either terrestrial or aquatic. An increase in the sedimentation rate is plausible, as chronological data shows that a similar thickness of sediment at the top of the core represents a shorter time period than at the bottom of the core (Wilkinson and Simpson, this volume). This phenomenon can be attributed to either increased sedimentation rates or increasing compaction with depth, or a combination of the two. Changes in the productivity of terrestrial plants could occur over a relatively short period of time, as a result of anthropogenically-induced changes, for example, a shift from forested land to agricultural land. De-forested land may suffer more erosion and rapid transport of leaf litter and other debris relative to forested land. Aquatic productivity, being sensitive to environmental change, may also change over a short period of time. Increases in nutrients from municipal and agricultural sources could contribute to enhanced algal productivity. Higher nutrient levels in Lake Winnipeg have been observed in recent years (Kling et al., 2002; Stainton et al., 2002). Kling et al. found that increased nutrients have contributed to increases in phytoplankton biomass and changes to species diversity in the past century. Stainton et al. found that increases in algal productivity are predominantly from nitrogen-fixing blue-green algae. Evidence of enhanced nutrient levels is also indicated by increased phosphorous concentrations (Simpson and Thorleifson, this volume; Mayer et al., this volume) and increased macrofossil abundances (Telka, this volume) in the top 20 cm or so of the 99-900 cores.

Although changes in sedimentation rate and post-depositional alteration may also be factors, the increase in HI and decrease in OI at the top of the cores would also be consistent with the hypothesis of increased algal productivity. Algae have higher HI values and fall into the Type II OM classification field. However, even the enhanced HI concentrations in the upper 20 cm are much smaller than would be expected for unaltered algal material (Meyers and Lallièr-Verges, 1999), suggesting that alteration of Lake Winnipeg OM may be significant.

Alteration of organic matter in Lake Winnipeg sediments

Carbon and nitrogen elemental and carbon isotopic analyses of the sediments indicate that the OM in Lake Winnipeg sediments was derived dominantly from aquatic sources, with periodic inputs from terrestrial sources (Buhay and Simpson, this volume). Given that carbon isotopic compositions are less subject to diagenetic alteration than Rock-Eval signatures in lacustrine material, this information suggests that diagenetic processes have altered Rock-Eval signatures to the extent that recognition of diverse sources is difficult.

The strong inverse relationship of HI to OI indicates that significant oxidative alteration of the source organic matter has occurred. This is explained by the fact that oxidation causes HI values to decrease and OI values to increase (Durand and Monin, 1980). Likely, the warm, shallow waters of Lake Winnipeg contribute to early oxidation of organic matter during summer months. Preferential preservation of the more refractory terrestrial OM may be at least partly responsible for the apparent terrestrial signature of the organic matter.

The changes in Rock-Eval parameters at the top of the cores can be explained by the degree of diagenetic alteration of the sedimentary OM following deposition. The fact that OM even at the top of the cores shows such a strong terrestrial signature and that algal productivity is known to be moderately high suggests that the majority of OM alteration occurs in the water column prior to deposition. However, diagenetic alteration likely continued after deposition, but at a much slower rate and to a lesser extent. Organic matter that has had more time to undergo diagenesis will often have smaller TOC and HI values and higher OI values, whereas recently deposited OM will often have higher TOC and HI values and lower OI values. These trends are evident in the Lake Winnipeg sediments and indicate that diagenetic alteration continues to occur after deposition down to a depth of approximately 20 cm. The processes involved may be oxidation, promoted by resuspension and bioturbation in the top 20 cm, or microbial anoxic degradation.

The fact that Rock-Eval parameters are very constant below a depth of approximately 20 cm suggests that diagenesis does not continue to any large extent below this depth over the time scale observed. This would suggest that diagenesis of OM in Lake Winnipeg occurs predominantly under oxidizing conditions and that anoxic bacteria do not play a significant role in OM degradation.

The shift in S3CO2, OICO2 and OIRE6 in core 8 at a depth of 120 cm from lower to higher values could represent a change in the type and/or amount of organic matter from primary sources at the time. However, the shift in values is barely perceptible in core 4, hence, it is unlikely that environmental changes are responsible for the shift in core 8, as environmental conditions would not affect only one of the cores. It is also unlikely, given the degree of OM alteration that appears to have occurred prior to and shortly after sedimentation, that any major differences in source OM would be recognizable at a depth of 120 cm. It is more likely that the shift observed at this depth is the result of localized diagenetic effects. An analytical artefact can be discounted due to re-ordering of the samples.

Preservation of floods in Lake Winnipeg sediments

Flood deposits might be expected to contain a higher concentration of terrestrial organic matter, due to influx of land plant debris. Because of rapid sedimentation and removal of sediments from the immediate proximity of the sediment water interface, both lacustrine and terrestrial organic matter may tend to be preserved in or just below flood deposits. However, there are no re-occurring, core-to-core correlateable layers of distinct Rock-Eval signature that could be considered flood deposits. This is likely the result of extensive recycling and alteration of the organic matter from the primary sources, or due to a lack of significant organic material in flood waters.

Thermal maturity may also be different between normal and flood sediments, as flooding would be expected to be accompanied by erosion and re-deposition. If the eroded material consists of sediments derived from sedimentary rock that contains organic matter at some elevated level of thermal maturity, this reworked material could easily comprise the dominant organic matter fraction in flood sediments. Hence a shift from immature lake sediments to something that appears to be at a higher level of thermal maturity could indicate the presence of an unusual erosion and re-deposition event. However, there are no obvious shifts in PI, a proxy for thermal maturity, which could be considered as resulting from flooding. At best, there are a few spikes that call for some consideration as possible flood events.

Metal remobilization at the sediment-water interface

The concentrations of several elements (Hg, Pb, P, U and Zn) co-vary with TOC. The depth profiles follow a straightforward pattern of near constant composition with an increase in the top 20 cm, possibly a coincidental relationship. On the other hand, increases in TOC could be causally related to increases in metal concentrations. The introduction of additional organic matter to the sediments would have an impact on the effective Eh of the sediments, which would in turn have an effect on the oxidation state of various metals, determining whether they are static (trapped) or mobilized (lost) from the system. Given the high degree of OM alteration that likely has occurred, it seems reasonable to assume that metals are continually being biologically recycled. As OM in the lake-bottom sediments degrades, metals are released and then migrate to the organic-rich sediment-water interface where they are again fixed through the formation of organo-metallic complexes. Increases in lead concentrations at the tops of the cores are however commonly attributed to leaded gasoline and seem less likely to be the result of metal recycling. Increases in the other metals could be the result of continual migration of and biological recycling of metals (Cline and Upchurch, 1973; Carlson et al., 1978; Coker et al., 1979; Farmer, 1991).

CONCLUSIONS

- Comparison of the Rock-Eval results to the literature implies that most of the lacustrine OM in Lake Winnipeg is derived from terrestrial sources (Type III OM). However, this inference is contradicted by C, N and ^{13}C results. Given that Rock-Eval parameters are not corrected for extensive early diagenesis, significant in shallow, warm lacustrine environments, the results may alternatively indicate complete diagenetic alteration of the primary source signature.

- Given that OM even at the tops of the cores shows such a strong terrestrial signature and that recent algal productivity is known to be moderately high, significant alteration of lacustrine OM is implied, producing a signature that resembles that of terrestrial material.

- Preferential preservation of the more refractory terrestrial OM may be at least partly responsible for the dominant terrestrial signature of the organic matter.

- Rock-Eval results suggest that the majority of OM alteration occurs under oxidizing conditions within the water column, prior to deposition. However, diagenetic alteration likely continues after deposition at a much slower rate and to a lesser extent.

- Increases in TOC and HI and decreases in OI in the top 22 cm of the cores could at least in part be explained by an increase in the productivity of aquatic plants.

- The shift in some Rock-Eval properties at a depth of 120 cm is likely the result of localized diagenesis occurring some time after deposition.

- There are no obvious re-occurring, core-to-core correlateable layers of distinct Rock-Eval signature that could be considered flood deposits, likely because the OM has been significantly altered.

- Co-variant increases of metals with TOC could be coincidental or the result of continual migration of and biological recycling of metals in the upper 20 cm of the lake-bottom sediments.

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Table 1. Description of measured Rock-Eval 6 parameters

Measured Parameter	Unit	Description
Qty	mg	amount of sample used
Tpeak	^{o}C	temperature at the top of the S2 peak
S1	mgHC/g sed	hydrocarbons released during heating to 300^{o}C, using a flame ionization detector (FID)
S2	mgHC/g sed	hydrocarbons released during ramped heating between 300^{o}C and 650^{o}C, using a FID
S'2	mgHC/g sed	a measure of the cumulative FID response after the sample has begun to cool
(S3)S3CO2	mgCO_2/g sed	carbon dioxide released during heating to 300^{o}C and during ramped heating
S3CO	mgCO/g sed	carbon monoxide released during heating to 300^{o}C and during ramped heating
S4CO2	mgCO_2/g sed	carbon dioxide released during oxidation phase
S4CO	mgCO/g sed	carbon monoxide released during oxidation phase
S5aCO2	mgCO_2/g sed	CO_2 responses to fixed temperature cut-offs
S5bCO2	mgCO_2/g sed	CO_2 responses to fixed temperature cut-offs
KFID	mVs/mgHC	response factor of FID; indicates machine was not recalibrated during a run

Table 2. Formulas and interpretative uses of calculated Rock-Eval 6 parameters

Calculated Parameter	Unit	Formula	Recent Sediments Interpretative Use
Tmax	°C	$Tpeak - (Tpeak_{std\ 55000} - T_{maxaccepted\ 55000})$	used for comparison with larger body of Rock-Eval II data
S2/S3	ratio	S2/S3CO2	indicator of type of organic matter (eg. land plants, algae)
PI	ratio	S1/(S1 + S2)	***Production Index***; indicator of level of thermal maturity
PC	wt %	[(S1 + S2)(0.083)] + [(S3CO2)(12/440)] + [(S3CO)(12/280)]	***Pyrolyzable Carbon***; reactive carbon in sample
RCCO2	wt %	(S4CO2)(12/440)	residual organic carbon from CO_2
RCCO	wt %	(S4CO)(12/280)	residual organic carbon from CO
RC	wt %	RCCO + RCCO2	***Residual (Organic) Carbon***; sum of inert carbon in sample
TOC	wt %	PC + RC	***Total Organic Carbon***; sum of all organic carbon in sample
HI	mgHC/gTOC	100*(S2/TOC)	***Hydrogen Index***; indicator of organic matter type
(OI)OICO2	$mgCO_2/gTOC$	100*(S3CO2/TOC)	***Oxygen Index***; indicator of amount of organic oxygen from CO_2
OICO	mgCO/gTOC	100*(S3CO/TOC)	indicator of amount of organic oxygen from CO
OIRE6		[(S3CO2)(100/TOC)(32/44)] + [(S3CO)(100/TOC)(16/28)]	indicator of amount of organic oxygen from CO and CO_2

Table 3. Rock-Eval results for Lake Winnipeg 99-900 core 4

Depth cm	Qty mg	Tpeak °C	Tmax °C	S1 mgHC/g sed	S2 mgHC/g sed	S'2 mgHC/g sed	(S3)S3CO2 $mgCO_2$/g sed	S3CO mgCO/g sed	S4CO2 $mgCO_2$/g sed	S4CO mgCO/g sed	S5aCO2 $mgCO_2$/g sed	S5bCO2 $mgCO_2$/g sed	KFID mVs/mgHC
0-1	99.8	467	422	0.15	1.84	0.01	4.34	1.42	47.90	3.30	0.00	2.90	1590.356
1-2	100.6	469	424	0.13	1.74	0.01	3.98	1.42	46.80	3.70	0.00	2.90	1590.356
2-3	100.3	466	421	0.15	1.75	0.01	4.21	1.29	47.40	2.90	0.00	2.80	1590.356
3-4	100.0	466	421	0.17	2.04	0.01	4.34	1.48	48.50	2.80	0.00	2.90	1590.356
4-5	100.6	466	421	0.17	1.86	0.01	4.36	1.37	48.30	2.80	0.00	3.00	1590.356
5-6	99.7	467	422	0.15	1.85	0.01	4.29	1.34	47.80	3.00	0.00	3.00	1590.356
6-7	100.2	467	422	0.17	2.00	0.01	4.35	1.45	48.70	3.00	0.00	3.10	1590.356
7-8	100.2	470	425	0.15	1.97	0.01	4.54	1.31	48.60	3.20	0.00	3.00	1590.356
8-9	99.6	468	423	0.13	1.80	0.01	4.44	1.43	48.20	2.70	0.00	3.00	1590.356
9-10	100.3	471	426	0.14	1.71	0.01	4.32	1.41	47.40	2.80	0.00	3.00	1590.356
10-11	100.4	474	429	0.12	1.69	0.01	4.47	1.27	47.60	3.10	0.00	3.00	1590.356
11-12	100.2	470	425	0.15	1.70	0.01	4.45	1.24	47.10	3.00	0.00	2.90	1590.356
12-13	100.4	471	426	0.12	1.62	0.01	4.37	1.43	46.80	2.80	0.00	2.80	1590.356
13-14	99.9	467	422	0.12	1.45	0.01	4.40	1.24	46.20	2.50	0.00	2.60	1590.356
14-15	100.6	467	422	0.23	1.45	0.01	4.28	1.24	44.90	3.10	0.00	2.60	1590.356
15-16	100.2	472	427	0.13	1.42	0.01	4.05	1.11	44.10	3.30	0.00	2.60	1590.356
16-17	100.7	468	423	0.10	1.20	0.01	3.65	1.06	39.80	3.60	0.00	2.20	1590.356
17-18	100.2	467	422	0.08	1.12	0.01	3.52	1.05	37.90	3.70	0.00	1.80	1590.356
18-19	99.7	466	421	0.09	1.01	0.00	3.67	1.04	37.50	3.40	0.00	1.70	1590.356
19-20	99.9	468	423	0.07	0.97	0.01	3.52	1.04	36.80	2.90	0.00	1.90	1590.356
20-21	100.2	468	423	0.07	0.94	0.00	3.49	1.09	36.70	2.30	0.00	1.70	1590.356
21-22	100.3	475	430	0.07	0.92	0.01	3.36	1.03	35.90	2.50	0.00	2.00	1590.356
22-23	100.6	468	423	0.07	0.85	0.01	3.32	0.91	34.80	2.60	0.00	1.90	1590.356
23-24	99.9	475	430	0.06	0.86	0.01	3.39	1.05	34.20	2.70	0.00	1.80	1590.356
24-25	100.7	473	428	0.06	0.87	0.01	3.41	0.94	34.50	2.90	0.00	1.70	1590.356
25-26	100.5	468	423	0.07	0.86	0.01	3.54	0.94	34.20	2.60	0.00	2.20	1590.356
26-27	100.2	475	430	0.06	0.77	0.00	3.44	1.03	33.20	2.40	0.00	2.50	1590.356
27-28	100.5	465	420	0.05	0.75	0.00	3.25	0.92	32.50	2.40	0.00	2.40	1590.356
28-29	100.9	471	426	0.05	0.77	0.00	3.25	1.04	32.50	2.40	0.00	2.40	1590.356
29-30	100.1	473	428	0.06	0.74	0.00	3.15	0.90	32.30	2.40	0.00	2.70	1590.356
30-31	100.1	475	430	0.09	0.77	0.00	3.03	0.86	32.60	2.30	0.00	2.70	1590.356

Table 3 continued

Depth cm	Qty mg	Tpeak °C	Tmax °C	S1 mgHC/g sed	S2 mgHC/g sed	S'2 mgHC/g sed	(S3)S3CO2 $mgCO_2$/g sed	S3CO mgCO/g sed	S4CO2 $mgCO_2$/g sed	S4CO mgCO/g sed	S5aCO2 $mgCO_2$/g sed	S5bCO2 $mgCO_2$/g sed	KFID mVs/mgHC
31-32	100.0	475	430	0.07	0.75	0.01	2.98	0.84	33.40	1.70	0.00	2.60	1590.356
32-33	99.9	469	424	0.05	0.72	0.00	3.09	0.79	31.40	2.30	0.00	2.60	1590.356
33-34	100.3	475	430	0.05	0.72	0.00	2.86	0.85	31.30	2.40	0.00	2.50	1590.356
34-35	101.1	470	425	0.05	0.77	0.01	3.18	0.85	32.30	2.20	0.00	2.50	1590.356
35-36	99.7	473	428	0.05	0.78	0.00	3.15	0.95	32.10	2.50	0.00	2.60	1590.356
36-37	100.2	467	422	0.05	0.70	0.00	3.15	0.85	31.70	1.90	0.00	2.50	1590.356
37-38	99.9	473	428	0.05	0.70	0.00	2.98	0.79	30.50	2.30	0.00	2.40	1590.356
38-39	100.3	469	424	0.05	0.70	0.00	2.98	0.96	30.90	2.30	0.00	2.60	1590.356
39-40	100.1	477	432	0.05	0.71	0.00	3.05	0.92	31.10	2.10	0.00	2.70	1590.356
40-41	100.4	473	428	0.04	0.68	0.00	3.06	0.80	31.70	1.50	0.00	2.70	1590.356
41-42	100.0	470	425	0.05	0.67	0.00	3.06	0.85	31.40	1.50	0.00	2.70	1590.356
42-43	100.5	478	433	0.04	0.67	0.00	3.12	0.88	31.30	2.20	0.00	2.80	1590.356
43-44	100.9	475	430	0.05	0.72	0.00	3.06	0.82	31.80	2.30	0.00	2.80	1590.356
44-45	99.9	467	422	0.05	0.71	0.00	3.05	0.84	32.10	2.10	0.00	2.90	1590.356
45-46	100.3	468	423	0.05	0.72	0.01	3.01	0.95	31.30	2.50	0.00	2.90	1590.356
46-47	100.4	470	425	0.07	0.74	0.00	3.00	0.80	31.40	2.40	0.00	2.70	1590.356
47-48	100.8	471	426	0.05	0.67	0.00	2.90	0.80	31.70	2.20	0.00	2.80	1590.356
48-49	100.1	467	422	0.05	0.68	0.00	3.09	0.96	30.30	2.30	0.00	2.70	1590.356
49-50	100.2	468	423	0.05	0.68	0.00	2.91	0.94	30.50	2.60	0.00	2.50	1590.356
50-51	100.4	467	422	0.05	0.69	0.00	3.08	0.87	31.40	1.80	0.00	2.50	1590.356
51-52	100.8	477	432	0.05	0.69	0.00	3.05	0.98	30.40	2.40	0.00	2.60	1590.356
52-53	100.1	483	438	0.04	0.69	0.00	2.97	0.77	30.80	2.10	0.00	2.50	1590.356
53-54	100.1	473	428	0.04	0.63	0.00	2.87	0.87	29.90	1.90	0.00	2.50	1590.356
54-55	100.2	475	430	0.05	0.67	0.00	2.97	0.82	30.20	1.90	0.00	2.30	1590.356
55-56	100.2	473	428	0.05	0.65	0.00	3.09	0.79	29.60	2.00	0.00	2.20	1590.356
56-57	99.8	472	427	0.04	0.62	0.00	3.00	0.84	29.20	2.10	0.00	2.20	1590.356
57-58	100.4	466	421	0.04	0.60	0.00	3.10	0.83	29.60	1.70	0.00	1.80	1590.356
58-59	100.5	468	423	0.05	0.62	0.00	3.24	0.95	29.80	2.10	0.00	2.20	1590.356
59-60	100.7	470	425	0.04	0.60	0.00	3.09	0.83	30.50	1.50	0.00	2.20	1590.356
60-61	100.0	473	428	0.04	0.63	0.00	3.04	0.91	30.40	1.50	0.00	1.70	1590.356
61-62	100.6	471	426	0.04	0.61	0.00	2.87	0.85	29.20	2.30	0.00	2.00	1590.356

Table 3 continued

Depth cm	Qty mg	Tpeak °C	Tmax °C	S1 mgHC/g sed	S2 mgHC/g sed	S'2 mgHC/g sed	(S3)S3CO2 $mgCO_2$/g sed	S3CO mgCO/g sed	S4CO2 $mgCO_2$/g sed	S4CO mgCO/g sed	S5aCO2 $mgCO_2$/g sed	S5bCO2 $mgCO_2$/g sed	KFID mVs/mgHC
62-63	99.7	475	430	0.05	0.59	0.00	2.74	0.74	29.10	2.00	0.00	2.50	1590.356
63-64	100.4	473	428	0.04	0.55	0.00	2.69	0.84	28.40	1.80	0.00	2.50	1590.356
64-65	100.4	471	426	0.04	0.58	0.00	2.87	0.95	28.40	1.80	0.00	2.30	1590.356
65-66	100.7	473	428	0.04	0.56	0.00	2.77	0.80	29.20	1.30	0.00	2.00	1590.356
66-67	100.9	473	428	0.04	0.57	0.00	2.79	0.75	28.30	1.90	0.00	2.10	1590.356
67-68	99.9	469	424	0.04	0.59	0.00	2.99	0.86	28.40	1.90	0.00	2.00	1590.356
68-69	99.9	473	428	0.04	0.62	0.00	2.84	0.92	29.20	2.00	0.00	2.00	1590.356
69-70	99.8	473	428	0.04	0.63	0.00	2.99	0.81	30.70	1.30	0.00	2.00	1590.356
70-71	100.3	469	424	0.05	0.68	0.00	3.00	0.96	30.00	2.20	0.00	2.10	1590.356
71-72	100.0	470	425	0.04	0.66	0.00	3.15	0.86	30.30	1.90	0.00	2.30	1590.356
72-73	100.5	477	432	0.05	0.66	0.00	3.04	0.82	30.30	2.20	0.00	2.40	1590.356
73-74	100.5	477	432	0.04	0.62	0.00	2.93	0.85	29.70	1.80	0.00	2.40	1590.356
74-75	100.0	473	428	0.04	0.62	0.00	3.18	0.98	29.90	2.10	0.00	2.50	1590.356
75-76	99.8	473	428	0.04	0.66	0.00	3.05	0.95	31.00	2.00	0.00	2.70	1590.356
76-77	100.5	467	422	0.05	0.68	0.00	3.25	1.00	31.90	1.90	0.00	2.70	1590.356
77-78	100.5	473	428	0.05	0.71	0.00	3.02	0.92	31.40	2.30	0.00	2.60	1590.356
78-79	100.5	469	424	0.05	0.70	0.00	3.09	0.96	32.00	2.00	0.00	2.70	1590.356
79-80	99.7	471	426	0.05	0.72	0.00	3.09	0.98	32.00	2.30	0.00	2.70	1590.356
80-81	99.8	469	424	0.05	0.68	0.00	3.12	0.90	31.20	2.00	0.00	2.60	1590.356
81-82	100.5	471	426	0.05	0.72	0.01	3.01	0.91	31.20	2.40	0.00	2.30	1590.356
82-83	101.1	470	425	0.04	0.67	0.00	3.09	0.81	31.30	2.10	0.00	2.30	1590.356
83-84	99.5	471	426	0.05	0.71	0.00	3.11	0.89	31.20	2.20	0.00	2.50	1590.356
84-85	100.1	475	430	0.04	0.69	0.00	3.00	0.76	31.00	2.10	0.00	2.60	1590.356
85-86	99.7	475	430	0.04	0.68	0.00	2.92	0.74	30.70	2.10	0.00	2.50	1590.356
86-87	100.4	469	424	0.04	0.62	0.00	3.00	0.80	29.40	1.90	0.00	2.40	1590.356
87-88	100.3	470	425	0.04	0.64	0.00	3.09	0.89	29.30	2.00	0.00	2.40	1590.356
88-89	100.4	468	423	0.04	0.66	0.00	3.16	0.92	29.70	2.10	0.00	2.50	1590.356
89-90	100.7	477	432	0.04	0.67	0.00	3.01	0.93	30.40	2.10	0.00	2.40	1590.356
90-91	100.0	469	424	0.04	0.55	0.00	2.92	0.77	28.90	1.50	0.00	2.60	1590.356
91-92	100.8	473	428	0.04	0.61	0.00	3.11	0.83	29.80	2.00	0.00	2.60	1590.356
92-93	100.1	473	428	0.04	0.62	0.00	2.91	0.74	30.10	1.80	0.00	2.50	1590.356

Table 3 continued

Depth cm	Qty mg	Tpeak °C	Tmax °C	S1 mgHC/g sed	S2 mgHC/g sed	S'2 mgHC/g sed	(S3)S3CO2 $mgCO_2$/g sed	S3CO mgCO/g sed	S4CO2 $mgCO_2$/g sed	S4CO mgCO/g sed	S5aCO2 $mgCO_2$/g sed	S5bCO2 $mgCO_2$/g sed	KFID mVs/mgHC
93-94	100.1	475	430	0.04	0.70	0.00	3.03	0.81	32.30	1.80	0.00	2.80	1590.356
94-95	99.7	477	432	0.05	0.73	0.00	3.05	0.80	32.70	1.90	0.00	2.70	1590.356
95-96	99.8	473	428	0.05	0.76	0.01	3.13	0.91	33.30	2.10	0.00	2.60	1590.356
96-97	99.6	472	427	0.04	0.60	0.00	2.92	0.91	29.20	2.30	0.00	2.20	1590.356
97-98	100.3	474	429	0.04	0.62	0.00	2.92	0.86	29.40	2.00	0.00	2.70	1590.356
98-99	100.1	475	430	0.04	0.58	0.00	2.77	0.84	28.60	1.80	0.00	2.30	1590.356
99-100	99.7	473	428	0.04	0.59	0.00	2.85	0.74	28.00	1.90	0.00	2.40	1590.356
100-101	100.7	467	422	0.04	0.57	0.00	2.91	0.76	27.50	2.00	0.00	2.30	1590.356
101-102	100.3	470	425	0.04	0.55	0.00	2.78	0.76	27.60	1.90	0.00	2.30	1590.356
102-103	100.4	473	428	0.03	0.53	0.00	2.76	0.72	27.60	1.90	0.00	2.50	1590.356
103-104	100.2	471	426	0.03	0.54	0.00	2.91	0.81	27.50	1.70	0.00	2.60	1590.356
104-105	100.0	468	423	0.04	0.56	0.00	2.89	0.73	27.90	1.80	0.00	2.60	1590.356
105-106	99.7	468	423	0.04	0.55	0.00	2.89	0.83	27.50	1.80	0.00	2.40	1590.356
106-107	100.7	473	428	0.04	0.56	0.00	2.84	0.83	28.10	1.90	0.00	2.40	1590.356
107-108	100.4	471	426	0.04	0.55	0.00	2.94	0.89	28.80	1.90	0.00	2.60	1590.356
108-109	100.3	475	430	0.03	0.55	0.00	2.78	0.77	28:50	1.80	0.00	2.50	1590.356
109-110	99.9	473	428	0.03	0.55	0.00	2.76	0.74	28.30	2.00	0.00	2.60	1590.356
110-111	99.9	471	426	0.04	0.55	0.00	2.77	0.77	29.30	1.30	0.00	2.60	1590.356
111-112	100.8	471	426	0.04	0.54	0.00	2.72	0.82	27.70	1.80	0.00	2.50	1590.356
112-113	100.3	467	422	0.03	0.50	0.00	2.70	0.71	26.20	1.90	0.00	2.20	1590.356
113-114	100.3	473	428	0.04	0.55	0.00	2.86	0.77	26.90	2.00	0.00	2.20	1590.356
114-115	100.6	469	424	0.04	0.57	0.00	2.75	0.77	28.10	2.10	0.00	2.30	1590.356
115-116	100.2	466	421	0.04	0.62	0.00	2.85	0.76	28.50	2.20	0.00	2.60	1590.356
116-117	100.2	473	428	0.04	0.61	0.01	2.79	0.73	28.90	2.10	0.00	2.60	1590.356
117-118	100.1	473	428	0.04	0.62	0.00	2.86	0.79	29.20	2.00	0.00	2.70	1590.356
118-119	100.1	475	430	0.04	0.58	0.00	2.76	0.80	28.60	1.90	0.00	2.40	1590.356
119-120	99.7	472	427	0.04	0.57	0.00	2.93	0.87	28.50	1.90	0.00	2.10	1590.356
120-121	100.2	476	431	0.03	0.51	0.00	3.08	0.69	27.80	1.60	0.00	1.90	1590.356
121-122	100.3	473	428	0.03	0.53	0.00	2.85	0.82	28.40	1.20	0.00	2.10	1590.356
122-123	100.6	468	423	0.03	0.52	0.00	2.82	0.73	28.40	1.10	0.00	2.10	1590.356
123-124	100.5	473	428	0.03	0.51	0.00	2.87	0.75	28.20	1.80	0.00	2.50	1590.356

Table 3 continued

Depth cm	Qty mg	Tpeak °C	Tmax °C	S1 mgHC/g sed	S2 mgHC/g sed	S'2 mgHC/g sed	(S3)S3CO2 $mgCO_2$/g sed	S3CO mgCO/g sed	S4CO2 $mgCO_2$/g sed	S4CO mgCO/g sed	S5aCO2 $mgCO_2$/g sed	S5bCO2 $mgCO_2$/g sed	KFID mVs/mgHC
124-125	100.0	467	422	0.03	0.56	0.00	2.91	0.80	28.80	1.90	0.00	2.60	1590.356
125-126	100.1	469	424	0.03	0.54	0.00	2.77	0.68	30.00	1.10	0.00	2.80	1590.356
126-127	100.4	464	419	0.03	0.53	0.00	2.71	0.84	28.00	1.80	0.00	2.70	1590.356
127-128	100.6	475	430	0.04	0.55	0.00	2.67	0.77	28.90	1.80	0.00	2.70	1590.356
128-129	99.7	470	425	0.04	0.53	0.00	2.70	0.85	27.90	2.30	0.00	2.80	1590.356
129-130	99.5	473	428	0.04	0.59	0.00	2.86	0.90	29.30	2.10	0.00	2.90	1590.356
130-131	99.8	473	428	0.04	0.61	0.00	2.78	0.76	30.00	2.20	0.00	2.90	1590.356
131-132	100.3	473	428	0.04	0.62	0.01	2.95	0.84	30.00	1.00	0.00	0.00	1590.356
132-133	100.0	473	428	0.04	0.60	0.01	2.92	0.76	29.50	1.90	0.00	2.80	1590.356
133-134	100.5	470	425	0.04	0.58	0.00	2.85	0.78	29.30	1.70	0.00	2.80	1590.356
134-135	101.1	469	424	0.03	0.55	0.00	2.82	0.72	29.60	1.20	0.00	2.70	1590.356
135-136	99.7	473	428	0.03	0.56	0.00	2.97	0.76	28.50	1.90	0.00	2.70	1590.356
136-137	100.9	469	424	0.03	0.53	0.00	2.88	0.85	28.10	1.80	0.00	2.70	1590.356
137-138	100.2	467	422	0.04	0.55	0.00	2.92	0.69	28.80	1.70	0.00	2.80	1590.356
138-139	100.6	473	428	0.03	0.54	0.00	2.81	0.79	28.40	1.90	0.00	2.80	1590.356
139-140	100.0	471	426	0.03	0.52	0.00	2.86	0.77	28.60	1.70	0.00	2.60	1590.356
140-141	99.9	473	428	0.03	0.53	0.00	2.79	0.86	29.40	1.40	0.00	2.70	1590.356
141-142	100.1	473	428	0.03	0.55	0.00	2.72	0.80	29.00	1.80	0.00	2.70	1590.356
142-143	100.6	475	430	0.03	0.57	0.00	2.72	0.81	29.50	1.80	0.00	2.60	1590.356
143-144	100.3	477	432	0.04	0.56	0.00	2.60	0.73	28.80	1.90	0.00	2.60	1590.356
144-145	100.4	475	430	0.04	0.54	0.00	2.57	0.74	28.20	2.10	0.00	2.60	1590.356
145-146	100.5	473	428	0.04	0.51	0.00	2.59	0.75	26.30	2.40	0.00	2.70	1590.356
146-147	100.4	473	428	0.03	0.53	0.00	2.79	0.74	27.50	1.90	0.00	2.80	1590.356
147-148	100.2	470	425	0.03	0.50	0.00	2.64	0.72	28.60	1.20	0.00	2.90	1590.356
148-149	100.5	475	430	0.03	0.54	0.00	2.75	0.72	27.90	1.70	0.00	2.90	1590.356
149-150	100.2	473	428	0.03	0.55	0.00	2.74	0.82	28.10	1.80	0.00	2.80	1590.356
150-151	100.3	473	428	0.03	0.54	0.00	2.77	0.79	28.90	1.40	0.00	2.90	1590.356
151-152	100.4	477	432	0.03	0.54	0.00	2.63	0.77	28.20	1.70	0.00	2.90	1590.356
152-153	100.0	470	425	0.03	0.52	0.00	2.88	0.75	28.00	1.70	0.00	2.90	1590.356
153-154	100.2	475	430	0.03	0.52	0.00	2.73	0.78	27.80	1.70	0.00	2.70	1590.356
154-155	100.7	471	426	0.03	0.56	0.00	2.92	0.73	29.30	2.10	0.00	2.60	1590.356

Table 3 continued

Depth cm	**Qty** mg	**Tpeak** °C	**Tmax** °C	**S1** mgHC/g sed	**S2** mgHC/g sed	**S'2** mgHC/g sed	**(S3)S3CO2** $mgCO_2$/g sed	**S3CO** mgCO/g sed	**S4CO2** $mgCO_2$/g sed	**S4CO** mgCO/g sed	**S5aCO2** $mgCO_2$/g sed	**S5bCO2** $mgCO_2$/g sed	**KFID** mVs/mgHC
155-156	100.2	473	428	0.03	0.58	0.00	2.99	0.84	31.00	2.00	0.00	2.70	1590.356
156-157	100.4	477	432	0.03	0.57	0.00	2.89	0.72	29.60	1.80	0.00	2.90	1590.356
157-158	100.3	475	430	0.03	0.55	0.00	2.90	0.69	29.10	1.60	0.00	2.90	1590.356
158-159	99.7	473	428	0.03	0.53	0.00	2.80	0.72	28.30	1.70	0.00	2.80	1590.356
159-160	100.0	477	432	0.03	0.49	0.00	2.69	0.71	27.30	1.70	0.00	2.60	1590.356
160-161	100.3	475	430	0.03	0.48	0.00	2.44	0.71	26.80	1.80	0.00	2.70	1590.356
161-162	100.0	470	425	0.04	0.50	0.00	2.39	0.67	26.80	2.00	0.00	2.70	1590.356

Table 3 continued

Depth cm	S2/S3	PI	PC wt %	RCCO2 wt %	RCCO wt %	RC wt %	TOC wt %	HI mgHC/gTOC	(OI)OICO2 mgCO$_2$/gTOC	OICO mgCO/gTOC	OIRE6 mgCO$_2$/gTOC
0-1	0.42	0.08	0.34	1.31	0.141	1.45	1.79	103	242	79	221
1-2	0.44	0.07	0.32	1.28	0.159	1.43	1.76	99	226	81	211
2-3	0.42	0.08	0.33	1.29	0.124	1.42	1.74	100	241	74	218
3-4	0.47	0.08	0.37	1.32	0.120	1.44	1.81	113	240	82	221
4-5	0.43	0.08	0.35	1.32	0.120	1.44	1.78	104	244	77	222
5-6	0.43	0.08	0.34	1.30	0.129	1.43	1.77	104	242	76	219
6-7	0.46	0.08	0.36	1.33	0.129	1.46	1.82	110	239	80	220
7-8	0.43	0.07	0.36	1.33	0.137	1.46	1.82	108	250	72	223
8-9	0.41	0.07	0.34	1.31	0.116	1.43	1.77	102	250	81	228
9-10	0.40	0.08	0.33	1.29	0.120	1.41	1.74	98	248	81	226
10-11	0.38	0.07	0.33	1.30	0.133	1.43	1.76	96	254	72	226
11-12	0.38	0.08	0.33	1.28	0.129	1.41	1.74	98	256	71	227
12-13	0.37	0.07	0.32	1.28	0.120	1.40	1.72	94	254	83	232
13-14	0.33	0.08	0.30	1.26	0.107	1.37	1.67	87	263	74	234
14-15	0.34	0.14	0.31	1.22	0.133	1.36	1.67	87	257	74	229
15-16	0.35	0.08	0.29	1.20	0.141	1.34	1.63	87	248	68	220
16-17	0.33	0.08	0.25	1.09	0.154	1.24	1.49	80	245	71	218
17-18	0.32	0.07	0.24	1.03	0.159	1.19	1.43	78	246	73	221
18-19	0.28	0.08	0.24	1.02	0.146	1.17	1.40	72	261	74	232
19-20	0.28	0.07	0.23	1.00	0.124	1.13	1.35	72	260	77	233
20-21	0.27	0.07	0.23	1.00	0.099	1.10	1.33	71	263	82	239
21-22	0.27	0.07	0.22	0.98	0.107	1.09	1.30	71	258	79	232
22-23	0.26	0.08	0.21	0.95	0.111	1.06	1.27	67	262	72	232
23-24	0.25	0.07	0.21	0.93	0.116	1.05	1.26	68	269	83	243
24-25	0.26	0.06	0.21	0.94	0.124	1.07	1.28	68	267	74	236
25-26	0.24	0.08	0.21	0.93	0.111	1.04	1.26	68	282	75	248
26-27	0.22	0.07	0.21	0.91	0.103	1.01	1.22	63	283	85	254
27-28	0.23	0.06	0.19	0.89	0.103	0.99	1.18	63	275	77	244
28-29	0.24	0.06	0.20	0.89	0.103	0.99	1.19	65	273	87	248
29-30	0.23	0.08	0.19	0.88	0.103	0.98	1.17	63	268	76	239
30-31	0.25	0.10	0.19	0.89	0.099	0.99	1.18	65	257	73	229

Table 3 continued

Depth cm	S2/S3	PI	PC wt %	RCCO2 wt %	RCCO wt %	RC wt %	TOC wt %	HI mgHC/gTOC	(OI)OICO2 mgCO_2/gTOC	OICO mgCO/gTOC	OIRE6 mgCO_2/gTOC
31-32	0.25	0.09	0.19	0.91	0.073	0.98	1.17	64	255	72	227
32-33	0.23	0.06	0.18	0.86	0.099	0.95	1.14	63	272	69	238
33-34	0.25	0.06	0.18	0.85	0.103	0.96	1.13	63	252	75	226
34-35	0.24	0.06	0.19	0.88	0.094	0.98	1.17	66	273	73	240
35-36	0.25	0.06	0.20	0.88	0.107	0.98	1.18	66	267	80	240
36-37	0.22	0.07	0.18	0.86	0.081	0.95	1.13	62	279	76	246
37-38	0.23	0.07	0.18	0.83	0.099	0.93	1.11	63	269	71	237
38-39	0.23	0.07	0.18	0.84	0.099	0.94	1.13	62	265	85	241
39-40	0.23	0.07	0.19	0.85	0.090	0.94	1.12	63	271	82	244
40-41	0.22	0.06	0.18	0.86	0.064	0.93	1.11	61	277	72	243
41-42	0.22	0.07	0.18	0.86	0.064	0.92	1.10	61	278	78	246
42-43	0.21	0.06	0.18	0.85	0.094	0.95	1.13	59	276	78	245
43-44	0.24	0.06	0.18	0.87	0.099	0.97	1.15	63	266	71	234
44-45	0.23	0.07	0.18	0.88	0.090	0.97	1.15	62	266	73	235
45-46	0.24	0.06	0.19	0.85	0.107	0.96	1.15	63	262	83	238
46-47	0.25	0.09	0.18	0.86	0.103	0.96	1.14	65	263	70	231
47-48	0.23	0.07	0.17	0.86	0.094	0.96	1.13	59	256	71	226
48-49	0.22	0.07	0.19	0.83	0.099	0.92	1.11	61	278	86	251
49-50	0.23	0.07	0.18	0.83	0.111	0.94	1.12	61	259	83	236
50-51	0.22	0.07	0.18	0.86	0.077	0.93	1.12	62	276	78	245
51-52	0.23	0.07	0.19	0.83	0.103	0.93	1.12	62	273	87	248
52-53	0.23	0.05	0.17	0.84	0.090	0.93	1.10	62	269	70	235
53-54	0.22	0.06	0.17	0.82	0.081	0.90	1.07	59	269	82	242
54-55	0.23	0.07	0.18	0.82	0.081	0.91	1.08	62	275	76	243
55-56	0.21	0.07	0.18	0.81	0.086	0.89	1.07	61	289	74	253
56-57	0.21	0.06	0.17	0.80	0.090	0.89	1.06	59	284	79	252
57-58	0.19	0.06	0.17	0.81	0.073	0.88	1.05	57	294	79	259
58-59	0.19	0.07	0.18	0.81	0.090	0.90	1.09	57	298	87	267
59-60	0.19	0.06	0.17	0.83	0.064	0.90	1.07	56	289	77	254
60-61	0.21	0.06	0.18	0.83	0.064	0.89	1.07	59	284	85	255
61-62	0.21	0.06	0.17	0.80	0.099	0.89	1.06	57	270	80	242

Table 3 continued

Depth cm	S2/S3	PI	PC wt %	RCCO2 wt %	RCCO wt %	RC wt %	TOC wt %	HI mgHC/gTOC	(OI)OICO2 mgCO$_2$/gTOC	OICO mgCO/gTOC	OIRE6 mgCO$_2$/gTOC
62-63	0.22	0.08	0.16	0.79	0.086	0.88	1.04	57	264	72	233
63-64	0.20	0.07	0.16	0.77	0.077	0.85	1.01	54	266	83	241
64-65	0.20	0.06	0.17	0.77	0.077	0.85	1.02	57	281	93	257
65-66	0.20	0.07	0.16	0.80	0.056	0.85	1.01	55	274	79	244
66-67	0.20	0.07	0.16	0.77	0.081	0.85	1.01	56	276	74	243
67-68	0.20	0.06	0.17	0.77	0.081	0.86	1.03	57	291	84	260
68-69	0.22	0.06	0.17	0.80	0.086	0.88	1.05	59	270	87	246
69-70	0.21	0.06	0.17	0.84	0.056	0.89	1.06	59	281	76	248
70-71	0.23	0.07	0.18	0.82	0.094	0.91	1.10	62	274	87	249
71-72	0.21	0.06	0.18	0.83	0.081	0.91	1.09	61	290	79	256
72-73	0.22	0.07	0.18	0.83	0.094	0.92	1.10	60	277	75	244
73-74	0.21	0.06	0.17	0.81	0.077	0.89	1.06	59	277	80	247
74-75	0.20	0.06	0.18	0.82	0.090	0.91	1.09	57	292	90	264
75-76	0.22	0.06	0.18	0.85	0.086	0.93	1.11	59	274	85	248
76-77	0.21	0.07	0.19	0.87	0.081	0.95	1.14	59	284	88	257
77-78	0.23	0.07	0.18	0.86	0.099	0.95	1.14	62	265	81	239
78-79	0.23	0.07	0.19	0.87	0.086	0.96	1.15	61	269	84	244
79-80	0.23	0.06	0.19	0.87	0.099	0.97	1.16	62	266	84	242
80-81	0.22	0.07	0.18	0.85	0.086	0.94	1.12	61	279	80	248
81-82	0.24	0.06	0.18	0.85	0.103	0.95	1.14	63	264	80	238
82-83	0.22	0.06	0.18	0.85	0.090	0.94	1.12	60	275	73	242
83-84	0.23	0.07	0.19	0.85	0.094	0.95	1.13	63	275	79	245
84-85	0.23	0.05	0.17	0.85	0.090	0.94	1.11	62	270	68	236
85-86	0.23	0.06	0.17	0.84	0.090	0.93	1.10	62	266	68	232
86-87	0.21	0.06	0.17	0.80	0.081	0.88	1.05	59	284	76	250
87-88	0.21	0.06	0.18	0.80	0.086	0.88	1.06	60	290	84	259
88-89	0.21	0.06	0.18	0.81	0.090	0.90	1.08	61	292	85	261
89-90	0.22	0.06	0.18	0.83	0.090	0.92	1.10	61	274	84	247
90-91	0.19	0.07	0.16	0.79	0.064	0.85	1.01	54	288	76	253
91-92	0.20	0.06	0.17	0.81	0.086	0.90	1.07	57	290	77	255
92-93	0.21	0.06	0.17	0.82	0.077	0.90	1.06	58	273	70	239

Table 3 continued

Depth cm	S2/S3	PI	PC wt %	RCCO2 wt %	RCCO wt %	RC wt %	TOC wt %	HI mgHC/gTOC	(OI)OICO2 $mgCO_2/gTOC$	OICO mgCO/gTOC	OIRE6 $mgCO_2/gTOC$
93-94	0.22	0.05	0.18	0.88	0.077	0.96	1.14	62	267	71	235
94-95	0.20	0.06	0.18	0.89	0.081	0.97	1.16	63	264	70	232
95-96	0.20	0.06	0.19	0.91	0.090	1.00	1.19	64	263	76	235
96-97	0.20	0.06	0.17	0.80	0.099	0.89	1.07	56	274	85	248
97-98	0.20	0.06	0.17	0.80	0.086	0.89	1.06	59	276	81	247
98-99	0.20	0.06	0.16	0.78	0.077	0.86	1.02	57	271	83	245
99-100	0.22	0.06	0.16	0.76	0.081	0.85	1.01	59	283	74	248
100-101	0.21	0.07	0.16	0.75	0.086	0.84	1.00	57	291	76	255
101-102	0.23	0.07	0.16	0.75	0.081	0.83	0.99	55	281	77	248
102-103	0.21	0.05	0.15	0.75	0.081	0.83	0.99	54	280	73	245
103-104	0.22	0.05	0.16	0.75	0.073	0.82	0.98	55	295	83	262
104-105	0.21	0.07	0.16	0.76	0.077	0.84	1.00	56	290	73	253
105-106	0.20	0.07	0.16	0.75	0.077	0.83	0.99	56	292	83	260
106-107	0.22	0.07	0.16	0.77	0.081	0.85	1.01	55	281	82	252
107-108	0.21	0.07	0.17	0.79	0.081	0.87	1.03	53	284	86	256
108-109	0.23	0.05	0.16	0.78	0.077	0.85	1.01	54	275	76	244
109-110	0.23	0.05	0.16	0.77	0.086	0.86	1.01	54	272	73	240
110-111	0.23	0.07	0.16	0.80	0.056	0.85	1.01	54	274	77	243
111-112	0.22	0.07	0.16	0.76	0.077	0.83	0.99	55	274	83	247
112-113	0.24	0.06	0.15	0.71	0.081	0.80	0.94	53	286	75	251
113-114	0.22	0.07	0.16	0.73	0.086	0.82	0.98	56	292	78	257
114-115	0.23	0.07	0.16	0.77	0.090	0.86	1.02	56	271	76	241
115-116	0.23	0.06	0.17	0.78	0.094	0.87	1.04	60	275	73	242
116-117	0.23	0.06	0.16	0.79	0.090	0.88	1.04	59	268	70	235
117-118	0.21	0.06	0.17	0.80	0.086	0.88	1.05	59	272	76	241
118-119	0.21	0.06	0.16	0.78	0.081	0.86	1.02	57	270	78	241
119-120	0.21	0.07	0.17	0.78	0.081	0.86	1.03	56	286	84	256
120-121	0.22	0.06	0.16	0.76	0.069	0.83	0.99	52	312	70	267
121-122	0.19	0.05	0.16	0.77	0.051	0.83	0.99	54	289	83	258
122-123	0.20	0.05	0.15	0.77	0.047	0.82	0.98	53	289	75	253
123-124	0.21	0.06	0.16	0.77	0.077	0.85	1.00	51	287	75	251

Table 3 continued

Depth cm	**S2/S3**	**PI**	**PC** wt %	**RCCO2** wt %	**RCCO** wt %	**RC** wt %	**TOC** wt %	**HI** mgHC/gTOC	**(OI)OICO2** $mgCO_2/gTOC$	**OICO** mgCO/gTOC	**OIRE6** $mgCO_2/gTOC$
124-125	0.19	0.05	0.16	0.79	0.081	0.87	1.03	54	283	78	250
125-126	0.19	0.05	0.15	0.82	0.047	0.87	1.02	53	272	67	236
126-127	0.20	0.05	0.16	0.76	0.077	0.84	1.00	53	272	84	246
127-128	0.21	0.07	0.15	0.79	0.077	0.87	1.02	54	262	76	233
128-129	0.20	0.07	0.16	0.76	0.099	0.86	1.02	52	266	84	241
129-130	0.21	0.06	0.17	0.80	0.090	0.89	1.06	56	270	85	245
130-131	0.22	0.06	0.16	0.82	0.094	0.91	1.07	57	258	71	228
131-132	0.21	0.06	0.17	0.82	0.043	0.86	1.03	60	286	81	255
132-133	0.21	0.06	0.17	0.80	0.081	0.89	1.05	57	278	72	243
133-134	0.20	0.06	0.16	0.80	0.073	0.87	1.03	56	275	76	243
134-135	0.20	0.05	0.16	0.81	0.051	0.86	1.01	54	278	71	242
135-136	0.19	0.05	0.16	0.78	0.081	0.86	1.02	55	291	74	254
136-137	0.18	0.05	0.16	0.77	0.077	0.84	1.00	53	286	85	257
137-138	0.19	0.07	0.16	0.79	0.073	0.86	1.02	54	288	68	248
138-139	0.19	0.05	0.16	0.77	0.081	0.86	1.01	53	277	78	246
139-140	0.18	0.05	0.16	0.78	0.073	0.85	1.01	52	284	76	250
140-141	0.19	0.05	0.16	0.80	0.060	0.86	1.02	52	273	85	247
141-142	0.20	0.05	0.16	0.79	0.077	0.87	1.02	54	266	78	238
142-143	0.21	0.05	0.16	0.80	0.077	0.88	1.04	55	261	77	234
143-144	0.22	0.07	0.15	0.79	0.081	0.87	1.02	55	255	72	227
144-145	0.21	0.07	0.15	0.77	0.090	0.86	1.01	54	254	73	227
145-146	0.20	0.07	0.15	0.72	0.103	0.82	0.97	53	268	78	239
146-147	0.19	0.05	0.15	0.75	0.081	0.83	0.99	54	283	75	249
147-148	0.19	0.06	0.15	0.78	0.051	0.83	0.98	51	270	73	238
148-149	0.20	0.05	0.15	0.76	0.073	0.83	0.99	55	278	73	244
149-150	0.20	0.05	0.16	0.77	0.077	0.84	1.00	55	274	82	246
150-151	0.19	0.05	0.16	0.79	0.060	0.85	1.01	54	276	79	246
151-152	0.21	0.05	0.15	0.77	0.073	0.84	0.99	54	264	77	237
152-153	0.18	0.05	0.16	0.76	0.073	0.84	0.99	52	290	75	254
153-154	0.19	0.05	0.15	0.76	0.073	0.83	0.98	53	277	79	247
154-155	0.19	0.05	0:16	0.80	0.090	0.89	1.05	53	278	69	242

Table 3 continued

Depth cm	S2/S3	PI	PC wt %	RCCO2 wt %	RCCO wt %	RC wt %	TOC wt %	HI mgHC/gTOC	(OI)OICO2 $mgCO_2/gTOC$	OICO mgCO/gTOC	OIRE6 $mgCO_2/gTOC$
155-156	0.19	0.05	0.17	0.85	0.086	0.93	1.10	53	272	77	242
156-157	0.20	0.05	0.16	0.81	0.077	0.88	1.04	55	276	69	240
157-158	0.19	0.05	0.16	0.79	0.069	0.86	1.02	54	285	68	246
158-159	0.19	0.05	0.15	0.77	0.073	0.84	1.00	53	280	72	245
159-160	0.18	0.06	0.15	0.74	0.073	0.82	0.96	51	279	73	245
160-161	0.20	0.06	0.14	0.73	0.077	0.81	0.95	51	258	75	231
161-162	0.21	0.07	0.14	0.73	0.086	0.82	0.96	52	250	70	222

Table 4. Rock-Eval results for Lake Winnipeg 99-900 core 8

Depth cm	Qty mg	Tpeak °C	Tmax °C	S1 mgHC/g sed	S2 mgHC/g sed	S'2 mgHC/g sed	(S3)S3CO2 mgCO$_2$/g sed	S3CO mgCO/g sed	S4CO2 mgCO$_2$/g sed	S4CO mgCO/g sed	S5aCO2 mgCO$_2$/g sed	S5bCO2 mgCO$_2$/g sed	KFID mVs/mgHC
0-1	100.1	475	430	0.18	2.54	0.01	4.52	1.47	51.10	2.80	0.00	3.60	1590.356
1-2	100.3	471	426	0.03	0.54	0.00	2.83	0.82	29.30	1.70	0.00	3.00	1590.356
2-3	100.2	465	420	0.15	1.96	0.01	4.57	1.31	48.80	3.00	0.00	3.60	1590.356
3-4	99.8	469	424	0.14	1.67	0.01	4.38	1.43	47.60	2.90	0.00	3.50	1590.356
4-5	100.5	471	426	0.13	1.62	0.01	4.35	1.25	46.90	3.20	0.00	3.40	1590.356
5-6	99.8	468	423	0.19	1.65	0.01	4.41	1.39	47.10	3.00	0.00	3.40	1590.356
6-7	99.9	471	426	0.14	1.62	0.01	4.25	1.31	47.00	3.00	0.00	3.50	1590.356
7-8	100.5	471	426	0.12	1.56	0.01	4.16	1.37	47.00	2.60	0.00	3.40	1590.356
8-9	99.8	470	425	0.12	1.51	0.01	4.24	1.20	46.30	2.90	0.00	3.40	1590.356
9-10	100.0	466	421	0.13	1.53	0.01	4.17	1.34	46.00	3.10	0.00	3.40	1590.356
10-11	100.5	473	428	0.13	1.49	0.01	4.13	1.15	45.90	2.80	0.00	3.30	1590.356
11-12	100.5	465	420	0.13	1.53	0.01	4.18	1.18	46.10	3.00	0.00	3.40	1590.356
12-13	100.6	468	423	0.10	1.47	0.01	4.21	1.37	46.00	2.70	0.00	3.30	1590.356
13-14	100.6	475	430	0.11	1.52	0.01	4.16	1.22	45.90	3.00	0.00	3.30	1590.356
14-15	100.5	475	430	0.10	1.48	0.01	4.14	1.16	45.60	2.90	0.00	3.30	1590.356
15-16	100.5	467	422	0.11	1.45	0.01	4.11	1.42	44.90	3.10	0.00	3.20	1590.356
16-17	100.5	464	419	0.14	1.94	0.01	4.42	1.37	49.00	2.60	0.00	3.50	1590.356
17-18	100.7	468	423	0.10	1.32	0.01	4.21	1.24	44.00	2.50	0.00	3.00	1590.356
18-19	99.9	465	420	0.09	1.19	0.01	4.07	1.27	39.90	3.70	0.00	2.80	1590.356
19-20	100.5	469	424	0.08	1.08	0.01	3.86	1.17	38.20	3.50	0.00	2.80	1590.356
20-21	100.3	475	430	0.08	1.01	0.00	3.80	1.10	37.60	3.00	0.00	2.90	1590.356
21-22	100.3	468	423	0.07	0.94	0.01	3.77	1.03	38.00	2.00	0.00	2.90	1590.356
22-23	100.3	468	423	0.07	0.92	0.00	3.58	1.12	35.80	2.80	0.00	2.80	1590.356
23-24	99.9	467	422	0.06	0.84	0.00	3.59	1.03	34.20	2.70	0.00	2.90	1590.356
24-25	100.2	469	424	0.06	0.83	0.00	3.46	1.02	34.50	2.30	0.00	2.90	1590.356
25-26	100.1	473	428	0.06	0.78	0.01	3.25	0.89	33.90	2.10	0.00	2.90	1590.356
26-27	100.0	471	426	0.05	0.76	0.00	3.19	1.01	33.20	2.40	0.00	2.80	1590.356
27-28	100.7	470	425	0.05	0.77	0.00	3.50	1.04	33.30	2.30	0.00	2.70	1590.356
28-29	100.2	471	426	0.05	0.78	0.00	3.46	1.00	33.30	2.40	0.00	2.80	1590.356
29-30	100.2	475	430	0.04	0.75	0.00	3.33	0.91	33.10	2.30	0.00	3.00	1590.356
30-31	100.3	471	426	0.05	0.74	0.00	3.22	0.87	33.40	2.10	0.00	3.10	1590.356

Table 4 continued

Depth cm	Qty mg	Tpeak °C	Tmax °C	S1 mgHC/g sed	S2 mgHC/g sed	S'2 mgHC/g sed	(S3)S3CO2 $mgCO_2$/g sed	S3CO mgCO/g sed	S4CO2 $mgCO_2$/g sed	S4CO mgCO/g sed	S5aCO2 $mgCO_2$/g sed	S5bCO2 $mgCO_2$/g sed	KFID mVs/mgHC
31-32	99.6	469	424	0.10	1.35	0.01	4.03	1.22	44.50	3.00	0.00	3.20	1590.356
32-33	99.9	471	426	0.05	0.74	0.00	3.36	0.90	33.20	2.00	0.00	3.20	1590.356
33-34	99.9	473	428	0.06	0.75	0.00	3.31	0.97	32.70	2.30	0.00	3.00	1590.356
34-35	100.3	473	428	0.05	0.76	0.00	3.24	0.93	32.90	2.10	0.00	3.10	1590.356
35-36	100.0	473	428	0.07	0.77	0.00	3.29	0.88	32.80	2.30	0.00	3.10	1590.356
36-37	100.3	472	427	0.05	0.75	0.00	3.27	0.99	32.40	2.20	0.00	2.90	1590.356
37-38	100.7	466	421	0.05	0.73	0.00	3.23	0.87	32.60	2.10	0.00	2.90	1590.356
38-39	100.1	470	425	0.06	0.72	0.00	3.27	0.90	31.90	2.30	0.00	3.00	1590.356
39-40	100.0	473	428	0.05	0.71	0.00	3.15	0.90	32.10	2.00	0.00	3.00	1590.356
40-41	99.7	470	425	0.05	0.76	0.01	3.15	0.96	32.40	2.20	0.00	3.00	1590.356
41-42	100.2	464	419	0.05	0.75	0.00	3.15	0.94	32.30	2.00	0.00	2.90	1590.356
42-43	100.2	473	428	0.04	0.72	0.00	3.13	0.95	32.40	1.90	0.00	3.00	1590.356
43-44	99.9	473	428	0.04	0.70	0.00	3.18	1.00	31.40	2.10	0.00	3.00	1590.356
44-45	100.3	473	428	0.05	0.69	0.00	3.10	0.82	32.20	1.40	0.00	3.00	1590.356
45-46	100.6	468	423	0.04	0.66	0.00	3.08	0.83	31.20	1.90	0.00	3.20	1590.356
46-47	101.0	473	428	0.04	0.67	0.00	2.98	0.78	32.20	1.30	0.00	3.20	1590.356
47-48	100.0	471	426	0.05	0.75	0.00	3.18	0.87	33.00	2.20	0.00	3.00	1590.356
48-49	99.7	475	430	0.05	0.68	0.00	3.09	0.86	31.70	1.90	0.00	3.20	1590.356
49-50	99.7	473	428	0.05	0.71	0.00	3.28	0.97	32.30	2.20	0.00	3.20	1590.356
50-51	100.7	469	424	0.04	0.70	0.00	3.14	0.95	31.80	2.00	0.00	3.10	1590.356
51-52	100.0	469	424	0.04	0.69	0.00	3.16	0.92	31.30	2.20	0.00	3.10	1590.356
52-53	100.3	473	428	0.04	0.69	0.00	3.08	0.93	30.70	2.40	0.00	3.00	1590.356
53-54	100.3	469	424	0.05	0.70	0.00	3.24	0.82	32.30	1.70	0.00	2.90	1590.356
54-55	100.6	468	423	0.06	0.73	0.00	3.35	0.96	33.10	2.20	0.00	3.00	1590.356
55-56	99.9	473	428	0.06	0.69	0.00	3.09	0.91	31.70	2.20	0.00	2.90	1590.356
56-57	100.2	473	428	0.06	0.66	0.00	3.04	0.80	30.70	2.10	0.00	2.90	1590.356
57-58	100.7	475	430	0.04	0.65	0.00	2.90	0.92	30.40	1.90	0.00	2.70	1590.356
58-59	100.5	467	422	0.04	0.62	0.00	3.07	0.92	30.00	1.90	0.00	2.70	1590.356
59-60	100.1	469	424	0.04	0.60	0.00	3.02	0.82	29.60	1.80	0.00	2.80	1590.356
60-61	100.1	477	432	0.04	0.63	0.00	3.03	0.90	30.30	1.80	0.00	2.80	1590.356
61-62	100.3	478	433	0.03	0.64	0.00	2.96	0.81	30.60	1.90	0.00	2.80	1590.356

Table 4 continued

Depth cm	Qty mg	Tpeak °C	Tmax °C	S1 mgHC/g sed	S2 mgHC/g sed	S'2 mgHC/g sed	(S3)S3CO2 $mgCO_2$/g sed	S3CO mgCO/g sed	S4CO2 $mgCO_2$/g sed	S4CO mgCO/g sed	S5aCO2 $mgCO_2$/g sed	S5bCO2 $mgCO_2$/g sed	KFID mVs/mgHC
62-63	100.1	467	422	0.04	0.65	0.00	3.24	0.94	31.30	1.70	0.00	2.80	1590.356
63-64	100.9	473	428	0.05	0.63	0.00	3.05	0.83	30.30	2.10	0.00	2.80	1590.356
64-65	99.7	477	432	0.05	0.62	0.00	3.13	0.79	30.10	1.90	0.00	2.80	1590.356
65-66	100.5	473	428	0.04	0.63	0.00	3.09	0.86	30.00	1.90	0.00	2.80	1590.356
66-67	100.2	472	427	0.04	0.63	0.00	3.11	0.77	31.10	1.30	0.00	2.80	1590.356
67-68	100.5	473	428	0.04	0.64	0.00	3.09	0.79	30.10	2.00	0.00	2.80	1590.356
68-69	100.1	473	428	0.04	0.67	0.00	3.08	0.84	30.60	2.00	0.00	2.80	1590.356
69-70	99.9	469	424	0.04	0.66	0.00	3.09	0.90	31.10	1.80	0.00	2.90	1590.356
70-71	100.2	469	424	0.05	0.66	0.00	3.06	0.94	31.40	1.70	0.00	2.80	1590.356
71-72	100.0	467	422	0.05	0.68	0.00	3.16	0.77	32.30	1.50	0.00	3.00	1590.356
72-73	99.9	477	432	0.04	0.67	0.01	3.01	0.77	30.90	1.90	0.00	2.80	1590.356
73-74	100.6	473	428	0.04	0.67	0.00	3.01	0.94	30.90	1.90	0.00	2.90	1590.356
74-75	100.5	473	428	0.04	0.65	0.00	3.13	0.81	30.40	2.00	0.00	2.90	1590.356
75-76	100.2	477	432	0.04	0.67	0.00	3.13	0.89	31.00	2.20	0.00	2.90	1590.356
76-77	100.0	475	430	0.04	0.61	0.00	3.03	0.78	30.00	2.00	0.00	2.80	1590.356
77-78	99.8	473	428	0.04	0.62	0.00	3.04	0.78	30.30	1.70	0.00	2.90	1590.356
78-79	100.4	476	431	0.04	0.65	0.00	3.02	0.82	30.90	1.80	0.00	2.80	1590.356
79-80	100.3	475	430	0.05	0.66	0.00	3.15	0.91	30.70	1.90	0.00	2.80	1590.356
80-81	100.4	477	432	0.05	0.68	0.01	3.18	0.83	31.30	1.90	0.00	2.90	1590.356
81-82	100.5	475	430	0.04	0.56	0.00	3.01	0.77	30.10	0.90	0.00	2.90	1590.356
82-83	99.7	475	430	0.03	0.58	0.00	3.00	0.76	29.20	1.70	0.00	2.90	1590.356
83-84	100.4	471	426	0.04	0.58	0.00	3.11	0.79	30.10	1.50	0.00	3.00	1590.356
84-85	100.0	477	432	0.03	0.58	0.00	2.95	0.84	29.80	1.80	0.00	2.90	1590.356
85-86	100.2	473	428	0.05	0.61	0.00	3.08	0.89	29.70	2.00	0.00	2.90	1590.356
86-87	100.0	477	432	0.05	0.62	0.00	3.07	0.74	30.10	1.90	0.00	2.70	1590.356
87-88	99.8	473	428	0.04	0.61	0.00	2.99	0.92	29.90	1.80	0.00	2.80	1590.356
88-89	100.0	477	432	0.04	0.61	0.00	3.04	0.79	30.20	1.70	0.00	2.90	1590.356
89-90	100.1	472	427	0.04	0.59	0.00	2.91	0.82	29.30	1.80	0.00	2.80	1590.356
90-91	100.2	473	428	0.04	0.61	0.00	3.05	0.78	29.40	2.00	0.00	3.00	1590.356
91-92	100.7	475	430	0.03	0.58	0.00	3.01	0.85	29.50	1.80	0.00	3.00	1590.356
92-93	101.0	469	424	0.03	0.59	0.00	3.06	0.77	29.50	1.80	0.00	2.90	1590.356

Table 4 continued

Depth cm	Qty mg	Tpeak °C	Tmax °C	S1 mgHC/g sed	S2 mgHC/g sed	S'2 mgHC/g sed	(S3)S3CO2 $mgCO_2/g$ sed	S3CO mgCO/g sed	S4CO2 $mgCO_2/g$ sed	S4CO mgCO/g sed	S5aCO2 $mgCO_2/g$ sed	S5bCO2 $mgCO_2/g$ sed	KFID mVs/mgHC
93-94	100.2	466	421	0.03	0.56	0.00	2.98	0.74	29.50	1.50	0.00	2.90	1590.356
94-95	100.1	473	428	0.04	0.57	0.00	2.94	0.83	29.30	1.80	0.00	2.90	1590.356
95-96	99.9	475	430	0.04	0.57	0.00	2.91	0.72	29.20	1.90	0.00	2.90	1590.356
96-97	100.7	469	424	0.05	0.59	0.01	3.15	0.78	29.10	1.80	0.00	2.90	1590.356
97-98	100.4	477	432	0.03	0.62	0.00	3.01	0.91	30.70	1.90	0.00	3.10	1590.356
98-99	100.5	475	430	0.03	0.57	0.00	2.91	0.79	29.60	1.20	0.00	3.10	1590.356
99-100	100.7	475	430	0.04	0.66	0.00	3.14	0.83	31.50	1.80	0.00	3.00	1590.356
100-101	100.2	475	430	0.04	0.62	0.00	3.09	0.85	30.90	1.90	0.00	3.00	1590.356
101-102	100.3	478	433	0.05	0.62	0.00	3.09	0.83	31.20	1.70	0.00	2.90	1590.356
102-103	100.7	473	428	0.04	0.60	0.00	3.07	0.83	32.10	0.90	0.00	2.90	1590.356
103-104	99.9	477	432	0.04	0.67	0.00	3.08	0.84	32.30	1.70	0.00	2.90	1590.356
104-105	99.8	473	428	0.04	0.65	0.00	3.13	0.86	31.50	1.90	0.00	2.90	1590.356
105-106	100.1	473	428	0.04	0.65	0.00	3.11	0.80	32.40	1.50	0.00	2.90	1590.356
106-107	100.4	475	430	0.04	0.64	0.00	3.17	0.82	31.00	2.00	0.00	3.00	1590.356
107-108	99.8	475	430	0.04	0.63	0.00	3.12	0.81	31.00	2.00	0.00	3.10	1590.356
108-109	100.7	477	432	0.04	0.68	0.01	3.15	0.86	32.10	1.70	0.00	3.00	1590.356
109-110	100.3	471	426	0.04	0.64	0.00	3.18	0.88	31.30	1.90	0.00	3.00	1590.356
110-111	100.5	476	431	0.05	0.64	0.00	3.03	0.79	30.80	1.90	0.00	2.90	1590.356
111-112	100.0	471	426	0.05	0.60	0.00	3.07	0.79	31.60	1.00	0.00	2.90	1590.356
112-113	100.8	475	430	0.05	0.66	0.00	3.22	0.79	32.30	1.20	0.00	3.10	1590.356
113-114	100.1	475	430	0.05	0.71	0.00	3.35	0.85	32.50	2.10	0.00	2.90	1590.356
114-115	99.9	473	428	0.04	0.66	0.00	3.15	0.84	31.20	1.90	0.00	2.90	1590.356
115-116	100.9	477	432	0.03	0.57	0.00	2.93	0.80	28.90	1.80	0.00	2.80	1590.356
116-117	99.6	473	428	0.04	0.58	0.00	2.96	0.75	29.70	1.80	0.00	2.80	1590.356
117-118	100.0	477	432	0.05	0.62	0.00	2.96	0.88	30.60	1.70	0.00	2.90	1590.356
118-119	99.9	470	425	0.04	0.64	0.00	2.87	0.71	30.90	2.00	0.00	3.00	1590.356
119-120	99.9	473	428	0.04	0.63	0.00	2.91	0.74	31.10	1.80	0.00	3.20	1590.356
120-121	100.4	475	430	0.03	0.61	0.00	2.91	0.72	31.00	1.80	0.00	3.20	1590.356
121-122	100.7	475	430	0.04	0.61	0.00	2.88	0.83	30.90	1.80	0.00	3.20	1590.356
122-123	100.6	470	425	0.03	0.59	0.00	2.82	0.72	32.10	1.00	0.00	3.20	1590.356
123-124	100.5	477	432	0.04	0.63	0.00	2.93	0.81	31.30	1.70	0.00	3.40	1590.356

Table 4 continued

Depth cm	Qty mg	Tpeak °C	Tmax °C	S1 mgHC/g sed	S2 mgHC/g sed	S'2 mgHC/g sed	(S3)S3CO2 $mgCO_2$/g sed	S3CO mgCO/g sed	S4CO2 $mgCO_2$/g sed	S4CO mgCO/g sed	S5aCO2 $mgCO_2$/g sed	S5bCO2 $mgCO_2$/g sed	KFID mVs/mgHC
124-125	100.4	475	430	0.04	0.63	0.00	2.97	0.89	30.80	1.90	0.00	3.20	1590.356
125-126	100.4	473	428	0.04	0.64	0.00	2.92	0.82	30.90	2.00	0.00	3.20	1590.356
126-127	100.3	471	426	0.07	0.64	0.00	2.92	0.87	31.00	2.00	0.00	3.20	1590.356
127-128	100.6	477	432	0.05	0.62	0.00	2.85	0.76	30.80	1.90	0.00	3.00	1590.356
128-129	100.8	471	426	0.05	0.64	0.00	3.05	0.87	31.30	1.80	0.00	3.00	1590.356
129-130	100.0	475	430	0.03	0.61	0.00	2.89	0.83	30.70	1.80	0.00	3.00	1590.356
130-131	100.6	475	430	0.04	0.62	0.00	2.85	0.74	30.90	1.60	0.00	3.10	1590.356
131-132	100.1	475	430	0.03	0.63	0.00	2.89	0.89	31.00	1.80	0.00	3.20	1590.356
132-133	100.4	473	428	0.04	0.63	0.00	2.95	0.86	31.70	1.40	0.00	3.20	1590.356
133-134	100.4	473	428	0.05	0.59	0.00	3.02	0.75	31.30	1.60	0.00	3.20	1590.356
134-135	100.5	475	430	0.04	0.62	0.00	2.84	0.83	30.60	2.10	0.00	3.20	1590.356
135-136	100.0	470	425	0.04	0.55	0.00	2.85	0.82	29.60	1.80	0.00	3.10	1590.356
136-137	99.9	473	428	0.03	0.52	0.00	2.70	0.70	28.70	1.70	0.00	3.00	1590.356
137-138	100.4	473	428	0.04	0.56	0.00	2.71	0.65	29.30	1.80	0.00	3.00	1590.356
138-139	100.2	477	432	0.03	0.52	0.00	2.61	0.70	28.40	1.80	0.00	3.00	1590.356
139-140	100.7	475	430	0.03	0.55	0.00	2.80	0.78	28.90	1.90	0.00	3.00	1590.356
140-141	100.1	475	430	0.03	0.58	0.00	2.86	0.70	29.60	1.50	0.00	2.90	1590.356
141-142	101.0	477	432	0.03	0.57	0.00	2.75	0.79	29.20	1.70	0.00	3.00	1590.356
142-143	100.5	477	432	0.05	0.58	0.00	2.68	0.87	30.30	1.30	0.00	2.90	1590.356
143-144	99.9	473	428	0.04	0.57	0.00	2.82	0.69	29.50	2.00	0.00	2.90	1590.356
144-145	100.0	477	432	0.04	0.62	0.00	2.77	0.70	31.10	1.60	0.00	3.00	1590.356
145-146	100.0	473	428	0.03	0.56	0.00	2.89	0.83	29.50	1.60	0.00	2.90	1590.356
146-147	100.4	473	428	0.04	0.57	0.00	2.76	0.83	29.30	1.90	0.00	2.90	1590.356
147-148	100.1	473	428	0.03	0.55	0.00	2.85	0.71	29.10	1.70	0.00	2.90	1590.356
148-149	100.3	468	423	0.03	0.53	0.00	2.91	0.80	28.90	1.70	0.00	3.00	1590.356
149-150	100.3	473	428	0.04	0.56	0.00	2.84	0.71	30.20	1.40	0.00	3.10	1590.356
150-151	100.1	477	432	0.04	0.61	0.00	2.82	0.79	30.50	1.90	0.00	3.20	1590.356
151-152	100.0	477	432	0.04	0.63	0.00	2.84	0.78	31.20	2.00	0.00	3.30	1590.356
152-153	100.4	473	428	0.04	0.60	0.00	2.97	0.69	30.70	1.90	0.00	3.00	1590.356
153-154	100.4	475	430	0.04	0.58	0.00	2.73	0.81	29.90	1.90	0.00	3.10	1590.356
154-155	100.0	470	425	0.03	0.54	0.00	2.79	0.77	30.70	1.10	0.00	3.00	1590.356

Table 4 continued

Depth cm	**Qty** mg	**Tpeak** °C	**Tmax** °C	**S1** mgHC/g sed	**S2** mgHC/g sed	**S'2** mgHC/g sed	**(S3)S3CO2** $mgCO_2$/g sed	**S3CO** mgCO/g sed	**S4CO2** $mgCO_2$/g sed	**S4CO** mgCO/g sed	**S5aCO2** $mgCO_2$/g sed	**S5bCO2** $mgCO_2$/g sed	**KFID** mVs/mgHC
155-156	100.0	467	422	0.03	0.55	0.00	2.90	0.81	30.50	1.30	0.00	3.10	1590.356
156-157	100.3	475	430	0.04	0.58	0.00	2.98	0.81	29.80	1.90	0.00	2.80	1590.356
157-158	100.4	473	428	0.03	0.58	0.00	2.92	0.80	30.70	1.90	0.00	2.90	1590.356

Table 4 continued

Depth cm	S2/S3	PI	PC wt %	RCCO2 wt %	RCCO wt %	RC wt %	TOC wt %	HI mgHC/gTOC	(OI)OICO2 mgCO2/gTOC	OICO mgCO/gTOC	OIRE6 $mgCO_2/gTOC$
0-1	0.56	0.07	0.41	1.39	0.120	1.51	1.93	132	235	76	214
1-2	0.19	0.06	0.16	0.80	0.073	0.87	1.03	52	274	79	245
2-3	0.43	0.07	0.36	1.33	0.129	1.46	1.82	108	252	72	224
3-4	0.38	0.08	0.33	1.30	0.124	1.42	1.75	95	250	82	228
4-5	0.37	0.07	0.32	1.28	0.137	1.42	1.73	93	251	72	224
5-6	0.37	0.10	0.33	1.28	0.129	1.41	1.75	95	253	80	229
6-7	0.38	0.08	0.32	1.28	0.129	1.41	1.73	94	246	76	222
7-8	0.38	0.07	0.31	1.28	0.111	1.39	1.70	92	244	80	223
8-9	0.36	0.07	0.30	1.26	0.124	1.39	1.69	89	251	71	223
9-10	0.37	0.08	0.31	1.25	0.133	1.39	1.70	90	246	79	224
10-11	0.36	0.08	0.30	1.25	0.120	1.37	1.67	89	248	69	219
11-12	0.37	0.08	0.30	1.26	0.129	1.39	1.69	91	248	70	220
12-13	0.35	0.06	0.30	1.25	0.116	1.37	1.67	88	251	82	230
13-14	0.37	0.07	0.30	1.25	0.129	1.38	1.68	90	247	73	221
14-15	0.36	0.06	0.29	1.24	0.124	1.37	1.66	89	249	70	221
15-16	0.35	0.07	0.30	1.22	0.133	1.36	1.66	87	248	86	229
16-17	0.44	0.07	0.35	1.34	0.111	1.45	1.80	108	246	76	222
17-18	0.31	0.07	0.29	1.20	0.107	1.31	1.59	83	264	78	237
18-19	0.29	0.07	0.27	1.09	0.159	1.25	1.52	78	268	84	243
19-20	0.28	0.07	0.25	1.04	0.150	1.19	1.44	75	267	81	241
20-21	0.27	0.07	0.24	1.03	0.129	1.15	1.40	72	272	79	243
21-22	0.25	0.07	0.23	1.04	0.086	1.12	1.35	69	279	76	246
22-23	0.26	0.07	0.23	0.98	0.120	1.10	1.32	69	270	85	245
23-24	0.23	0.06	0.22	0.93	0.116	1.05	1.27	66	284	81	253
24-25	0.24	0.07	0.21	0.94	0.099	1.04	1.25	66	276	82	248
25-26	0.24	0.07	0.20	0.92	0.090	1.01	1.21	64	268	73	237
26-27	0.24	0.06	0.20	0.91	0.103	1.01	1.21	63	265	84	240
27-28	0.22	0.06	0.21	0.91	0.099	1.01	1.21	63	288	86	258
28-29	0.23	0.06	0.21	0.91	0.103	1.01	1.22	64	284	82	254
29-30	0.23	0.06	0.20	0.90	0.099	1.00	1.20	63	278	76	246
30-31	0.23	0.06	0.19	0.91	0.090	1.00	1.19	62	270	73	238

Table 4 continued

Depth cm	S2/S3	PI	PC wt %	RCCO2 wt %	RCCO wt %	RC wt %	TOC wt %	HI mgHC/gTOC	(OI)OICO2 mgCO2/gTOC	OICO mgCO/gTOC	OIRE6 $mgCO_2/gTOC$
31-32	0.33	0.07	0.28	1.21	0.129	1.34	1.62	83	248	75	223
32-33	0.22	0.07	0.20	0.91	0.086	0.99	1.19	62	283	76	249
33-34	0.23	0.07	0.20	0.89	0.099	0.99	1.19	63	278	82	249
34-35	0.23	0.06	0.20	0.90	0.090	0.99	1.18	64	274	79	244
35-36	0.23	0.08	0.20	0.89	0.099	0.99	1.19	65	276	74	243
36-37	0.23	0.06	0.20	0.88	0.094	0.98	1.18	64	278	84	250
37-38	0.23	0.06	0.19	0.89	0.090	0.98	1.17	62	276	74	243
38-39	0.22	0.07	0.19	0.87	0.099	0.97	1.16	62	282	78	249
39-40	0.23	0.07	0.19	0.88	0.086	0.96	1.15	62	274	78	244
40-41	0.24	0.07	0.19	0.88	0.094	0.98	1.17	65	269	82	242
41-42	0.24	0.06	0.19	0.88	0.086	0.97	1.16	65	272	81	244
42-43	0.23	0.05	0.19	0.88	0.081	0.97	1.15	62	271	82	244
43-44	0.22	0.06	0.19	0.86	0.090	0.95	1.14	62	280	88	254
44-45	0.22	0.06	0.18	0.88	0.060	0.94	1.12	62	277	73	243
45-46	0.21	0.06	0.18	0.85	0.081	0.93	1.11	59	277	75	245
46-47	0.22	0.06	0.17	0.88	0.056	0.93	1.11	60	269	70	236
47-48	0.22	0.06	0.19	0.90	0.094	1.00	1.18	63	268	73	237
48-49	0.22	0.06	0.18	0.86	0.081	0.95	1.13	60	274	76	243
49-50	0.22	0.06	0.19	0.88	0.094	0.98	1.17	61	281	83	251
50-51	0.22	0.06	0.19	0.87	0.086	0.95	1.14	61	275	83	248
51-52	0.22	0.06	0.19	0.85	0.094	0.95	1.13	61	279	81	249
52-53	0.22	0.06	0.18	0.84	0.103	0.94	1.12	61	274	83	246
53-54	0.22	0.07	0.19	0.88	0.073	0.95	1.14	61	284	72	248
54-55	0.22	0.08	0.20	0.90	0.094	1.00	1.20	61	280	80	250
55-56	0.22	0.08	0.19	0.86	0.094	0.96	1.14	60	270	80	242
56-57	0.22	0.08	0.18	0.84	0.090	0.93	1.10	60	275	72	242
57-58	0.22	0.06	0.18	0.83	0.081	0.91	1.09	60	267	85	243
58-59	0.20	0.06	0.18	0.82	0.081	0.90	1.08	58	285	85	256
59-60	0.20	0.06	0.17	0.81	0.077	0.88	1.06	57	286	78	253
60-61	0.21	0.06	0.18	0.83	0.077	0.90	1.08	58	280	83	252
61-62	0.22	0.05	0.17	0.83	0.081	0.92	1.09	59	272	75	241

Table 4 continued

Depth cm	S2/S3	PI	PC wt %	RCCO2 wt %	RCCO wt %	RC wt %	TOC wt %	HI mgHC/gTOC	(OI)OICO2 mgCO2/gTOC	OICO mgCO/gTOC	OIRE6 $mgCO_2/gTOC$
62-63	0.20	0.06	0.19	0.85	0.073	0.93	1.11	58	291	85	260
63-64	0.21	0.07	0.18	0.83	0.090	0.92	1.09	58	279	76	247
64-65	0.20	0.07	0.17	0.82	0.081	0.90	1.08	58	291	73	253
65-66	0.20	0.07	0.18	0.82	0.081	0.90	1.08	59	287	80	254
66-67	0.20	0.06	0.17	0.85	0.056	0.90	1.08	58	289	71	251
67-68	0.21	0.06	0.17	0.82	0.086	0.91	1.08	59	286	73	250
68-69	0.22	0.06	0.18	0.83	0.086	0.92	1.10	61	280	76	247
69-70	0.21	0.06	0.18	0.85	0.077	0.92	1.11	60	279	81	250
70-71	0.22	0.07	0.18	0.86	0.073	0.93	1.11	59	275	85	248
71-72	0.22	0.07	0.18	0.88	0.064	0.95	1.12	60	281	68	243
72-73	0.22	0.06	0.17	0.84	0.081	0.92	1.10	61	274	70	239
73-74	0.22	0.06	0.18	0.84	0.081	0.92	1.11	61	272	85	247
74-75	0.21	0.06	0.18	0.83	0.086	0.91	1.09	60	287	74	251
75-76	0.21	0.05	0.18	0.85	0.094	0.94	1.12	60	279	79	248
76-77	0.20	0.06	0.17	0.82	0.086	0.90	1.07	57	282	73	247
77-78	0.20	0.06	0.17	0.83	0.073	0.90	1.07	58	284	73	248
78-79	0.22	0.05	0.17	0.84	0.077	0.92	1.09	59	276	75	243
79-80	0.21	0.08	0.18	0.84	0.081	0.92	1.10	60	286	83	255
80-81	0.21	0.06	0.18	0.85	0.081	0.94	1.12	61	284	74	249
81-82	0.19	0.07	0.16	0.82	0.039	0.86	1.02	55	294	75	257
82-83	0.19	0.05	0.17	0.80	0.073	0.87	1.03	56	290	73	253
83-84	0.19	0.06	0.17	0.82	0.064	0.89	1.06	55	295	75	257
84-85	0.20	0.05	0.17	0.81	0.077	0.89	1.06	55	279	79	248
85-86	0.20	0.07	0.18	0.81	0.086	0.89	1.07	57	287	83	256
86-87	0.20	0.07	0.17	0.82	0.081	0.90	1.07	58	286	69	247
87-88	0.20	0.06	0.17	0.82	0.077	0.89	1.07	57	280	86	253
88-89	0.20	0.06	0.17	0.82	0.073	0.90	1.07	57	285	74	249
89-90	0.20	0.06	0.17	0.80	0.077	0.88	1.04	57	279	79	248
90-91	0.20	0.06	0.17	0.80	0.086	0.89	1.06	58	288	74	252
91-92	0.19	0.05	0.17	0.80	0.077	0.88	1.05	55	286	81	255
92-93	0.19	0.05	0.17	0.80	0.077	0.88	1.05	56	292	73	254

Table 4 continued

Depth cm	**S2/S3**	**PI**	**PC** wt %	**RCCO2** wt %	**RCCO** wt %	**RC** wt %	**TOC** wt %	**HI** mgHC/gTOC	**(OI)OICO2** mgCO2/gTOC	**OICO** mgCO/gTOC	**OIRE6** $mgCO_2/gTOC$
93-94	0.19	0.06	0.16	0.80	0.064	0.87	1.03	54	289	72	251
94-95	0.19	0.06	0.17	0.80	0.077	0.88	1.04	55	282	80	251
95-96	0.20	0.06	0.16	0.80	0.081	0.88	1.04	55	280	69	243
96-97	0.19	0.08	0.17	0.79	0.077	0.87	1.04	57	302	75	262
97-98	0.21	0.05	0.18	0.84	0.081	0.92	1.09	57	275	83	248
98-99	0.20	0.05	0.16	0.81	0.051	0.86	1.02	56	285	77	251
99-100	0.21	0.05	0.18	0.86	0.077	0.94	1.12	59	281	74	247
100-101	0.20	0.06	0.18	0.84	0.081	0.92	1.10	56	281	77	249
101-102	0.20	0.08	0.18	0.85	0.073	0.92	1.10	56	281	76	248
102-103	0.20	0.06	0.17	0.88	0.039	0.91	1.09	55	283	76	249
103-104	0.22	0.06	0.18	0.88	0.073	0.95	1.13	59	272	74	240
104-105	0.21	0.06	0.18	0.86	0.081	0.94	1.12	58	279	77	247
105-106	0.21	0.06	0.18	0.88	0.064	0.95	1.12	58	277	71	242
106-107	0.20	0.06	0.18	0.85	0.086	0.93	1.11	58	286	74	250
107-108	0.20	0.06	0.18	0.85	0.086	0.93	1.11	57	282	73	247
108-109	0.22	0.05	0.18	0.88	0.073	0.95	1.13	60	279	76	246
109-110	0.20	0.06	0.18	0.85	0.081	0.94	1.12	57	285	79	252
110-111	0.21	0.07	0.17	0.84	0.081	0.92	1.10	58	277	72	242
111-112	0.20	0.08	0.17	0.86	0.043	0.91	1.08	56	285	73	249
112-113	0.20	0.07	0.18	0.88	0.051	0.93	1.11	59	289	71	251
113-114	0.21	0.07	0.19	0.89	0.090	0.98	1.17	61	287	73	250
114-115	0.21	0.06	0.18	0.85	0.081	0.93	1.11	59	283	76	249
115-116	0.19	0.06	0.16	0.79	0.077	0.86	1.03	55	285	78	251
116-117	0.20	0.06	0.16	0.81	0.077	0.89	1.05	55	282	71	245
117-118	0.21	0.08	0.17	0.83	0.073	0.91	1.08	57	274	81	246
118-119	0.22	0.05	0.17	0.84	0.086	0.93	1.09	59	262	65	228
119-120	0.22	0.06	0.17	0.85	0.077	0.92	1.09	58	266	68	233
120-121	0.21	0.05	0.16	0.85	0.077	0.92	1.09	56	268	66	233
121-122	0.21	0.06	0.17	0.84	0.077	0.92	1.09	56	265	76	236
122-123	0.21	0.05	0.16	0.88	0.043	0.92	1.08	55	262	67	229
123-124	0.22	0.05	0.17	0.85	0.073	0.93	1.10	57	267	74	237

Table 4 continued

Depth cm	**S2/S3**	**PI**	**PC** wt %	**RCCO2** wt %	**RCCO** wt %	**RC** wt %	**TOC** wt %	**HI** mgHC/gTOC	**(OI)OICO2** mgCO2/gTOC	**OICO** mgCO/gTOC	**OIRE6** $mgCO_2/gTOC$
124-125	0.21	0.05	0.17	0.84	0.081	0.92	1.10	54	289	72	251
125-126	0.22	0.05	0.17	0.84	0.086	0.93	1.10	55	282	80	251
126-127	0.22	0.10	0.18	0.85	0.086	0.93	1.11	55	280	69	243
127-128	0.22	0.08	0.17	0.84	0.081	0.92	1.09	57	302	75	262
128-129	0.21	0.07	0.18	0.85	0.077	0.93	1.11	57	275	83	248
129-130	0.21	0.05	0.17	0.84	0.077	0.91	1.08	56	285	77	251
130-131	0.22	0.06	0.16	0.84	0.069	0.91	1.08	59	281	74	247
131-132	0.22	0.05	0.17	0.85	0.077	0.92	1.09	56	281	77	249
132-133	0.21	0.06	0.17	0.86	0.060	0.92	1.10	56	281	76	248
133-134	0.20	0.08	0.17	0.85	0.069	0.92	1.09	55	283	76	249
134-135	0.22	0.06	0.17	0.83	0.090	0.92	1.09	59	272	74	240
135-136	0.19	0.06	0.16	0.81	0.077	0.88	1.05	58	279	77	247
136-137	0.19	0.06	0.15	0.78	0.073	0.86	1.00	58	277	71	242
137-138	0.21	0.07	0.15	0.80	0.077	0.88	1.03	58	286	74	250
138-139	0.20	0.06	0.15	0.77	0.077	0.85	1.00	57	282	73	247
139-140	0.20	0.05	0.16	0.79	0.081	0.87	1.03	60	279	76	246
140-141	0.20	0.05	0.16	0.81	0.064	0.87	1.03	57	285	79	252
141-142	0.21	0.05	0.16	0.80	0.073	0.87	1.03	58	277	72	242
142-143	0.22	0.08	0.16	0.83	0.056	0.88	1.04	56	285	73	249
143-144	0.20	0.07	0.16	0.80	0.086	0.89	1.05	59	289	71	251
144-145	0.22	0.06	0.16	0.85	0.069	0.92	1.08	61	287	73	250
145-146	0.19	0.06	0.16	0.80	0.069	0.87	1.04	59	283	76	249
146-147	0.21	0.06	0.16	0.80	0.081	0.88	1.04	55	285	78	251
147-148	0.19	0.06	0.16	0.79	0.073	0.87	1.02	55	282	71	245
148-149	0.18	0.06	0.16	0.79	0.073	0.86	1.02	57	274	81	246
149-150	0.20	0.07	0.16	0.82	0.060	0.88	1.04	59	262	65	228
150-151	0.22	0.06	0.16	0.83	0.081	0.91	1.08	58	266	68	233
151-152	0.22	0.06	0.17	0.85	0.086	0.94	1.10	56	268	66	233
152-153	0.20	0.06	0.16	0.84	0.081	0.92	1.08	56	265	76	236
153-154	0.21	0.06	0.16	0.82	0.081	0.90	1.06	55	262	67	229
154-155	0.19	0.05	0.16	0.84	0.047	0.88	1.04	57	267	74	237

Table 4 continued

Depth cm	S2/S3	PI	PC wt %	RCCO2 wt %	RCCO wt %	RC wt %	TOC wt %	HI mgHC/gTOC	(OI)OICO2 mgCO2/gTOC	OICO mgCO/gTOC	OIRE6 $mgCO_2/gTOC$
155-156	0.19	0.06	0.16	0.83	0.056	0.89	1.05	52	276	77	245
156-157	0.19	0.06	0.17	0.81	0.081	0.89	1.06	55	281	76	248
157-158	0.20	0.05	0.16	0.84	0.081	0.92	1.08	54	270	74	238

Table 5. Duplicate analyses of Rock-Eval for Lake Winnipeg 99-900 core 4

	Qty mg		Tpeak °C		Tmax °C		S1 mgHC/g sed		S2 mgHC/g sed		S'2 mgHC/g sed		(S3)S3CO2 $mgCO_2$/g sed		S3CO mgCO/g sed	
Sample No	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**
Core-4-46-47cm	100.4	100.0	470	466	425	421	0.07	0.05	0.74	0.72	0.00	0.00	3.16	3.30	0.83	0.93
Core-4-62-63cm	99.7	100.2	475	473	430	428	0.05	0.04	0.59	0.58	0.00	0.00	2.90	2.95	0.77	0.84
Core-4-74-75cm	100.0	100.5	473	471	428	426	0.04	0.04	0.62	0.65	0.00	0.00	3.23	3.09	0.99	0.96
Core-4-84-85cm	100.1	100.1	475	473	430	428	0.04	0.05	0.69	0.71	0.00	0.00	2.91	3.25	0.74	0.85
Core-4-98-99cm	100.1	100.5	475	478	430	433	0.04	0.04	0.58	0.61	0.00	0.00	2.63	2.98	0.82	0.80
Core-4-102-103cm	100.4	100.6	473	473	428	428	0.03	0.04	0.53	0.54	0.00	0.00	2.71	2.89	0.71	0.78
Core-4-115-116cm	100.2	100.5	466	475	421	430	0.04	0.04	0.62	0.61	0.00	0.00	2.73	2.81	0.74	0.81
Core-4-121-122cm	100.3	100.8	473	473	428	428	0.03	0.03	0.53	0.53	0.00	0.00	2.87	2.86	0.82	0.87
Core-4-133-134cm	100.5	100.6	470	469	425	424	0.04	0.04	0.58	0.58	0.00	0.00	2.77	2.87	0.77	0.90
Core-4-140-141cm	99.9	100.6	473	473	428	428	0.03	0.03	0.53	0.55	0.00	0.00	2.88	2.74	0.88	0.69
Core-4-156-157cm	100.4	99.9	477	470	432	425	0.03	0.03	0.57	0.57	0.00	0.00	2.95	2.78	0.73	0.79
Core-4-160-161cm	100.3	100.0	475	471	430	426	0.03	0.03	0.48	0.48	0.00	0.00	2.61	2.64	0.74	0.73
RSD (%)	0.29		0.59		0.65		13.94		1.98		n/a		4.33		7.84	
Precision (%)	0.58		1.17		1.3		27.87		3.97		n/a		8.67		15.68	

Table 5 continued

Sample No	S4CO2 mgCO$_2$/g sed		S4CO mgCO/g sed		S5aCO2 mgCO$_2$/g sed		S5bCO2 mgCO$_2$/g sed		KFID mVs/mgHC		PI		PC wt %		RCCO2 wt %	
	1st	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**
Core-4-46-47cm	31.4	31.3	2.4	2.6	0.0	0.0	2.7	2.7	1590.4	1590.4	0.09	0.06	0.10	0.10	0.86	0.85
Core-4-62-63cm	29.1	28.7	2.0	2.1	0.0	0.0	2.5	2.4	1590.4	1590.4	0.07	0.07	0.09	0.09	0.79	0.78
Core-4-74-75cm	29.9	29.6	2.1	2.3	0.0	0.0	2.5	2.5	1590.4	1590.4	0.06	0.06	0.10	0.10	0.82	0.81
Core-4-84-85cm	31.0	32.3	2.1	1.5	0.0	0.0	2.6	2.6	1590.4	1590.4	0.06	0.06	0.09	0.10	0.85	0.88
Core-4-98-99cm	28.6	28.9	1.8	2.0	0.0	0.0	2.3	2.3	1590.4	1590.4	0.06	0.06	0.09	0.09	0.78	0.79
Core-4-102-103cm	27.6	27.9	1.9	1.8	0.0	0.0	2.5	2.5	1590.4	1590.4	0.06	0.06	0.08	0.08	0.75	0.76
Core-4-115-116cm	28.5	29.1	2.2	2.2	0.0	0.0	2.6	2.6	1590.4	1590.4	0.06	0.06	0.09	0.09	0.78	0.79
Core-4-121-122cm	28.4	27.8	1.2	1.8	0.0	0.0	2.1	2.0	1590.4	1590.4	0.06	0.05	0.08	0.08	0.77	0.76
Core-4-133-134cm	29.3	29.3	1.7	1.8	0.0	0.0	2.8	2.8	1590.4	1590.4	0.06	0.06	0.08	0.09	0.80	0.80
Core-4-140-141cm	29.4	29.2	1.4	1.7	0.0	0.0	2.7	2.6	1590.4	1590.4	0.05	0.05	0.08	0.08	0.80	0.80
Core-4-156-157cm	29.6	29.3	1.8	1.8	0.0	0.0	2.9	2.9	1590.4	1590.4	0.06	0.05	0.08	0.08	0.81	0.80
Core-4-160-161cm	26.8	27.0	1.8	1.6	0.0	0.0	2.7	2.6	1590.4	1590.4	0.07	0.06	0.07	0.07	0.73	0.74
RSD (%)	1.22		10.74		n/a		1.6		0		11.62		3.33		1.09	
Precision (%)	2.43		21.49		n/a		3.19		0		23.25		6.66		2.18	

Table 5 continued

Sample No	RCCO wt %		RC wt %		TOC wt %		HI mgHC/gTOC		(OI)OICO2 $mgCO_2/gTOC$		OICO mgCO/gTOC		OIRE6 $mgCO_2/gTOC$	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Core-4-46-47cm	0.103	0.111	0.96	0.97	1.06	1.07	70	67	298	308	78	87	261	274
Core-4-62-63cm	0.086	0.090	0.88	0.87	0.97	0.96	61	60	299	307	79	88	263	274
Core-4-74-75cm	0.090	0.099	0.91	0.91	1.01	1.01	61	64	320	306	98	95	289	277
Core-4-84-85cm	0.090	0.064	0.94	0.95	1.03	1.05	67	68	283	310	72	81	247	272
Core-4-98-99cm	0.077	0.086	0.86	0.87	0.95	0.96	61	64	277	310	86	83	251	273
Core-4-102-103cm	0.081	0.077	0.83	0.84	0.91	0.92	58	59	298	314	78	85	261	277
Core-4-115-116cm	0.094	0.094	0.87	0.89	0.96	0.98	65	62	284	287	77	83	251	256
Core-4-121-122cm	0.051	0.077	0.83	0.83	0.91	0.91	58	58	315	314	90	96	281	283
Core-4-133-134cm	0.073	0.077	0.87	0.88	0.95	0.97	61	60	292	296	81	93	259	268
Core-4-140-141cm	0.060	0.073	0.86	0.87	0.94	0.95	56	58	306	288	94	73	276	251
Core-4-156-157cm	0.077	0.077	0.88	0.88	0.96	0.96	59	59	307	290	76	82	267	258
Core-4-160-161cm	0.077	0.069	0.81	0.80	0.88	0.87	55	55	297	303	84	84	264	268
RSD (%)	10.82		1.81		0.9		2.22		3.79		7.67		3.93	
Precision (%)	21.63		1.61		1.8		4.43		7.58		15.34		7.85	

Table 6. Duplicate analyses of Rock-Eval for Lake Winnipeg 99-900 core 8

	Qty mg		Tpeak °C		Tmax °C		S1 mgHC/g sed		S2 mgHC/g sed		S'2 mgHC/g sed		(S3)S3CO2 $mgCO_2$/g sed		S3CO mgCO/g sed	
Sample No	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Core-8-25-26cm	100.1	100.4	473	475	428	430	0.06	0.04	0.78	0.78	0.01	0.00	3.25	3.38	0.89	0.94
Core-8-35-36cm	100.0	100.4	473	467	428	422	0.07	0.05	0.77	0.79	0.00	0.00	3.29	3.35	0.88	0.99
Core-8-38-39cm	100.1	100.7	470	471	425	426	0.06	0.04	0.72	0.73	0.00	0.00	3.27	3.25	0.90	0.97
Core-8-50-51cm	100.7	100.7	469	477	424	432	0.04	0.04	0.70	0.70	0.00	0.00	3.14	3.10	0.95	0.93
Core-8-59-60cm	100.1	100.1	469	468	424	423	0.04	0.04	0.60	0.61	0.00	0.00	3.02	3.08	0.82	0.85
Core-8-74-75cm	100.5	99.9	473	470	428	425	0.04	0.04	0.65	0.62	0.00	0.00	3.13	3.16	0.81	0.77
Core-8-86-87cm	100.0	100.2	477	471	432	426	0.05	0.04	0.62	0.64	0.00	0.00	3.07	3.13	0.74	0.84
Core-8-101-102cm	100.3	100.5	478	476	433	431	0.05	0.03	0.62	0.59	0.00	0.00	3.09	3.10	0.83	0.73
Core-8-114-115cm	99.9	100.6	473	477	428	432	0.04	0.04	0.66	0.66	0.00	0.00	3.15	3.17	0.84	0.88
Core-8-121-122cm	100.7	100.6	475	477	430	432	0.04	0.03	0.61	0.62	0.00	0.00	2.88	2.91	0.83	0.84
Core-8-133-134cm	100.4	100.2	473	473	428	428	0.05	0.03	0.59	0.61	0.00	0.00	3.02	2.95	0.75	0.82
Core-8-147-148cm	100.1	100.3	473	451	428	406	0.03	0.03	0.55	0.60	0.00	0.00	2.85	2.76	0.71	0.70
RSD (%)	0.26		1.11		1.23		22.53		2.36		n/a		1.39		5.37	
Precision (%)	0.52		2.22		2.45		45.06		4.72		n/a		2.79		10.74	

Table 6 continued

Sample No	S4CO2 mgCO_2/g sed		S4CO mgCO/g sed		S5aCO2 mgCO_2/g sed		S5bCO2 mgCO_2/g sed		KFID mVs/mgHC		PI		PC wt %		RCCO2 wt %	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Core-8-25-26cm	33.9	33.7	2.1	2.3	0.0	0.0	2.9	2.9	1590.4	1590.4	0.07	0.05	0.11	0.11	0.92	0.92
Core-8-35-36cm	32.8	32.7	2.3	2.1	0.0	0.0	3.1	3.1	1590.4	1590.4	0.08	0.06	0.11	0.11	0.89	0.89
Core-8-38-39cm	31.9	31.9	2.3	2.3	0.0	0.0	3.0	2.9	1590.4	1590.4	0.07	0.06	0.10	0.11	0.87	0.87
Core-8-50-51cm	31.8	31.8	2.0	2.0	0.0	0.0	3.1	3.1	1590.4	1590.4	0.06	0.05	0.10	0.10	0.87	0.87
Core-8-59-60cm	29.6	30.6	1.8	1.2	0.0	0.0	2.8	2.8	1590.4	1590.4	0.06	0.06	0.09	0.09	0.81	0.83
Core-8-74-75cm	30.4	31.1	2.0	1.5	0.0	0.0	2.9	2.9	1590.4	1590.4	0.06	0.06	0.09	0.09	0.83	0.85
Core-8-86-87cm	30.1	29.9	1.9	1.9	0.0	0.0	2.7	2.8	1590.4	1590.4	0.07	0.06	0.09	0.09	0.82	0.82
Core-8-101-102cm	31.2	31.0	1.7	1.6	0.0	0.0	2.9	2.9	1590.4	1590.4	0.08	0.05	0.09	0.08	0.85	0.85
Core-8-114-115cm	31.2	31.0	1.9	2.1	0.0	0.0	2.9	2.9	1590.4	1590.4	0.06	0.05	0.09	0.10	0.85	0.85
Core-8-121-122cm	30.9	31.0	1.8	1.9	0.0	0.0	3.2	3.3	1590.4	1590.4	0.06	0.05	0.09	0.09	0.84	0.85
Core-8-133-134cm	31.3	30.7	1.6	1.8	0.0	0.0	3.2	3.1	1590.4	1590.4	0.08	0.05	0.09	0.09	0.85	0.84
Core-8-147-148cm	29.1	30.2	1.7	1.2	0.0	0.0	2.9	3.0	1590.4	1590.4	0.06	0.05	0.08	0.08	0.79	0.82
RSD (%)	1.18		11.10		n/a		1.54		0.00		18.98		3.74		1.04	
Precision (%)	2.35		22.20		n/a		3.07		0.00		37.96		7.48		2.09	

Table 6 continued

Sample No	RCCO wt %		RC wt %		TOC wt %		HI mgHC/gTOC		(OI)OICO2 $mgCO_2/gTOC$		OICO mgCO/gTOC		OIRE6 $mgCO_2/gTOC$	
	1st	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**
Core-8-25-26cm	0.090	0.099	1.01	1.02	1.12	1.13	71	69	290	299	79	83	256	265
Core-8-35-36cm	0.099	0.090	0.99	0.98	1.10	1.09	70	72	299	307	80	91	263	275
Core-8-38-39cm	0.099	0.099	0.97	0.97	1.07	1.08	67	68	306	301	84	90	271	270
Core-8-50-51cm	0.086	0.086	0.95	0.95	1.05	1.05	67	67	299	295	90	89	269	265
Core-8-59-60cm	0.077	0.051	0.88	0.89	0.97	0.98	62	62	311	314	85	87	275	278
Core-8-74-75cm	0.086	0.064	0.91	0.91	1.00	1.00	65	62	313	316	81	77	274	274
Core-8-86-87cm	0.081	0.081	0.90	0.90	0.99	0.99	63	65	310	316	75	85	268	278
Core-8-101-102cm	0.073	0.069	0.92	0.91	1.01	0.99	61	60	306	313	82	74	269	270
Core-8-114-115cm	0.081	0.090	0.93	0.94	1.02	1.04	65	63	309	305	82	85	272	270
Core-8-121-122cm	0.077	0.081	0.92	0.93	1.01	1.02	60	61	285	285	82	82	254	254
Core-8-133-134cm	0.069	0.077	0.92	0.91	1.01	1.00	58	61	299	295	74	82	260	261
Core-8-147-148cm	0.073	0.051	0.87	0.88	0.95	0.96	58	63	300	288	75	73	261	251
RSD (%)	11.31		0.62		0.77		2.50		1.45		5.19		1.64	
Precision (%)	22.62		1.24		1.54		5.01		2.91		10.39		3.27	

Table 7. Results for analysis of standard 9107 run with Lake Winnipeg 99-900 core 4

Sample No	Qty mg	Tpeak °C	Tmax °C	S1 mgHC/g sed	S2 mgHC/g sed	S'2 mgHC/g sed	(S3)S3CO2 $mgCO_2$/g sed	S3CO mgCO/g sed	S4CO2 $mgCO_2$/g sed	S4CO mgCO/g sed	S5aCO2 $mgCO_2$/g sed	S5bCO2 $mgCO_2$/g sed
9107	99.8	487	442	1.01	11.74	0.06	0.56	0.21	115.4	18.8	0.0	9.3
9107	100.3	487	442	0.85	11.73	0.07	0.58	0.20	114.4	17.8	0.0	9.2
9107	100.0	487	442	1.04	12.26	0.07	0.52	0.15	114.8	18.6	0.0	9.3
9107	99.7	487	442	0.84	11.63	0.07	0.62	0.18	116.0	18.7	0.0	9.4
9107	99.9	485	440	1.00	12.12	0.07	0.78	0.24	115.2	18.4	0.0	9.4
9107	100.0	487	442	0.87	11.79	0.07	0.58	0.21	116.2	18.4	0.0	9.6
9107	100.3	487	442	0.87	11.53	0.07	0.65	0.19	117.9	17.9	0.0	9.8
9107	100.1	484	439	0.93	12.12	0.07	0.89	0.13	117.5	18.0	0.0	9.5
9107	100.2	485	440	0.87	11.78	0.07	0.69	0.07	115.7	18.6	0.0	9.4
9107	99.8	487	442	0.86	11.54	0.07	0.75	0.31	117.7	18.2	0.0	9.5
9107	100.0	486	441	0.91	12.25	0.07	0.84	0.25	118.0	19.0	0.0	9.7
9107	100.3	491	446	0.83	11.57	0.07	0.69	0.22	119.0	18.2	0.0	10.0
9107	100.4	489	444	0.93	11.77	0.07	0.67	0.16	117.8	18.5	0.0	9.7
9107	100.8	489	444	0.86	11.46	0.07	0.69	0.23	118.8	18.2	0.0	9.8
9107	100.2	488	443	0.87	11.57	0.07	0.65	0.22	117.9	18.8	0.0	9.8
Mean	100.1	487	442	0.90	11.79	0.07	0.68	0.20	116.8	18.4	0.0	9.6
St.Dev.	0.28	1.75	1.75	0.07	0.27	0.00	0.10	0.06	1.50	0.35	0.00	0.23

Table 7 continued

Sample No	**KFID** mVs/mgHC	**PI**	**PC** wt %	**RCCO2** wt %	**RCCO** wt %	**RC** wt %	**TOC** wt %	**HI** mgHC/gTOC	**(OI)OICO2** $mgCO_2/gTOC$	**OICO** mgCO/gTOC	**OIRE6** $mgCO_2/gTOC$
9107	1590.356	0.08	1.07	3.15	0.806	3.95	5.02	235	11	4	10
9107	1590.356	0.07	1.06	3.12	0.763	3.88	4.94	239	12	4	11
9107	1590.356	0.08	1.12	3.13	0.797	3.93	5.05	244	10	3	9
9107	1590.356	0.07	1.05	3.16	0.801	3.97	5.02	233	12	4	11
9107	1590.356	0.08	1.11	3.14	0.789	3.93	5.04	242	15	5	14
9107	1590.356	0.07	1.07	3.17	0.789	3.96	5.03	236	12	4	11
9107	1590.356	0.07	1.04	3.22	0.767	3.98	5.02	231	13	4	12
9107	1590.356	0.07	1.09	3.20	0.771	3.98	5.07	240	18	3	15
9107	1590.356	0.07	1.06	3.16	0.797	3.95	5.01	237	14	1	11
9107	1590.356	0.07	1.05	3.21	0.780	3.99	5.04	230	15	6	14
9107	1590.356	0.07	1.11	3.22	0.814	4.03	5.14	240	16	5	14
9107	1590.356	0.07	1.04	3.25	0.780	4.03	5.07	230	14	4	12
9107	1590.356	0.07	1.07	3.21	0.793	4.01	5.08	233	13	3	11
9107	1590.356	0.07	1.04	3.24	0.780	4.02	5.06	228	14	5	13
9107	1590.356	0.07	1.05	3.22	0.806	4.02	5.07	230	13	4	12
Mean	1590.356	0.07	1.07	3.19	0.789	3.98	5.04	235	13	4	12
St.Dev.	0.00	0.00	0.03	0.04	0.02	0.04	0.04	4.99	2.03	1.16	1.69

Table 8. Results for analysis of standard 9107 run with Lake Winnipeg 99-900 core 8

Sample No	Qty mg	Tpeak °C	Tmax °C	S1 mgHC/g sed	S2 mgHC/g sed	S'2 mgHC/g sed	(S3)S3CO2 $mgCO_2$/g sed	S3CO mgCO/g sed	S4CO2 $mgCO_2$/g sed	S4CO mgCO/g sed	S5aCO2 $mgCO_2$/g sed	S5bCO2 $mgCO_2$/g sed
9107	100.5	486	441	0.93	11.72	0.07	0.57	0.24	118.3	18.0	0.0	9.6
9107	100.6	487	442	0.88	11.36	0.07	0.71	0.22	120.7	17.9	0.0	9.9
9107	99.9	486	441	0.93	11.61	0.07	0.68	0.26	119.4	18.0	0.0	9.7
9107	100.2	486	441	0.86	11.15	0.07	0.68	0.28	120.9	17.6	0.0	10.0
9107	100.5	491	446	0.90	11.64	0.07	0.64	0.13	116.8	18.5	0.0	10.0
9107	100.2	490	445	0.90	11.64	0.07	0.65	0.21	116.6	18.9	0.0	9.8
9107	100.6	488	443	0.89	11.65	0.07	0.70	0.26	118.4	18.0	0.0	9.6
9107	100.6	489	444	0.92	11.51	0.07	0.61	0.21	117.8	18.5	0.0	10.2
9107	100.6	488	443	0.89	11.55	0.07	0.67	0.26	119.3	17.7	0.0	9.8
9107	100.6	490	445	0.91	11.62	0.07	0.69	0.10	116.8	18.9	0.0	10.0
9107	99.7	488	443	0.92	11.32	0.07	0.59	0.22	118.2	18.5	0.0	10.1
9107	100.1	487	442	0.90	11.53	0.07	0.63	0.25	118.9	18.2	0.0	9.8
9107	100.3	486	441	0.89	11.55	0.07	0.65	0.25	119.1	17.9	0.0	9.5
9107	100.1	488	443	0.94	11.63	0.07	0.66	0.23	117.5	18.3	0.0	9.5
9107	100.2	488	443	0.93	11.65	0.07	0.66	0.21	115.5	19.4	0.0	10.3
9107	100.5	489	444	0.90	11.51	0.07	0.63	0.16	118.4	18.1	0.0	9.5
Mean	100.3	488	443	0.91	11.54	0.07	0.65	0.22	118.3	18.3	0.0	9.8
St.Dev.	0.28	1.57	1.57	0.02	0.15	0.00	0.04	0.05	1.46	0.49	0.00	0.25

Table 8 continued

Sample No	**KFID** mVs/mgHC	**PI**	**PC** wt %	**RCCO2** wt %	**RCCO** wt %	**RC** wt %	**TOC** wt %	**HI** mgHC/gTOC	**(OI)OICO2** $mgCO_2/gTOC$	**OICO** mgCO/gTOC	**OIRE6** $mgCO_2/gTOC$
9107	1590.356	0.07	1.07	3.23	0.771	4.00	5.07	233	11	5	11
9107	1590.356	0.07	1.03	3.29	0.767	4.06	5.09	225	14	4	12
9107	1590.356	0.07	1.06	3.26	0.771	4.03	5.09	229	13	5	12
9107	1590.356	0.07	1.01	3.30	0.754	4.05	5.06	222	13	6	13
9107	1590.356	0.07	1.05	3.19	0.793	3.98	5.03	233	13	3	11
9107	1590.356	0.07	1.06	3.18	0.810	3.99	5.05	232	13	4	12
9107	1590.356	0.07	1.06	3.23	0.771	4.00	5.06	232	14	5	13
9107	1590.356	0.07	1.05	3.21	0.793	4.01	5.06	229	12	4	11
9107	1590.356	0.07	1.05	3.25	0.759	4.01	5.06	230	13	5	12
9107	1590.356	0.07	1.05	3.19	0.810	4.00	5.05	231	14	2	11
9107	1590.356	0.07	1.03	3.22	0.793	4.02	5.05	226	12	4	11
9107	1590.356	0.07	1.05	3.24	0.780	4.02	5.07	229	12	5	12
9107	1590.356	0.07	1.05	3.25	0.767	4.01	5.06	230	13	5	12
9107	1590.356	0.07	1.06	3.20	0.784	3.99	5.05	232	13	5	12
9107	1590.356	0.07	1.06	3.15	0.831	3.98	5.04	233	13	4	12
9107	1590.356	0.07	1.04	3.23	0.776	4.00	5.04	230	13	3	11

Mean	1590.356	0.07	1.05	3.23	0.783	4.01	5.06	230	13	4	12
St.Dev.	0.00	0.00	0.01	0.04	0.02	0.02	0.02	3.13	0.81	1.01	0.68

Table 9. Results for analysis of standards 9107 and TCA-8010 run at end of Lake Winnipeg 99-900 analyses

Sample No	Qty mg	Tpeak °C	Tmax °C	S1 mgHC/g sed	S2 mgHC/g sed	S'2 mgHC/g sed	(S3)S3CO2 $mgCO_2/g$ sed	S3CO mgCO/g sed	S4CO2 $mgCO_2/g$ sed	S4CO mgCO/g sed	S5aCO2 $mgCO_2/g$ sed	S5bCO2 $mgCO_2/g$ sed
9107	100.6	485	440	0.93	12.04	0.07	0.77	0.26	117.4	18.3	0.0	9.6
9107	100.5	487	442	0.88	11.55	0.07	0.63	0.17	117.8	18.7	0.0	9.8
TCA8010	100.3	477	432	0.00	0.03	0.00	0.98	0.11	1.8	0.1	0.4	0.8
TCA8010	100.3	483	438	0.00	0.03	0.00	1.00	0.10	1.8	0.0	0.4	0.7
TCA8010	100.1	493	448	0.00	0.04	0.00	1.11	0.16	2.0	0.1	0.2	0.6
TCA8010	100.0	464	419	0.00	0.04	0.00	1.04	0.15	1.9	0.1	0.3	0.7
TCA8010	100.5	490	445	0.00	0.06	0.00	1.04	0.17	2.1	0.1	0.4	0.9
TCA8010	99.9	462	417	0.00	0.14	0.00	0.99	0.09	2.3	0.1	0.3	0.9
TCA8010	100.6	477	432	0.00	0.04	0.00	1.08	0.12	1.8	0.1	0.4	0.8
TCA8010	99.9	490	445	0.00	0.05	0.00	1.01	0.11	2.0	0.1	0.4	0.8

TCA8010

Mean	100.2	480	435	0.00	0.05	0.00	1.03	0.13	2.0	0.1	0.4	0.8
St.Dev.	0.27	11.80	11.80	0.00	0.04	0.00	0.05	0.03	0.18	0.04	0.08	0.10

Table 9 continued

Sample No	KFID mVs/mgHC	PI	PC wt %	RCCO2 wt %	RCCO wt %	RC wt %	TOC wt %	HI mgHC/gTOC	(OI)OICO2 $mgCO_2/gTOC$	OICO mgCO/gTOC	OIRE6 $mgCO_2/gTOC$
9107	1590.356	0.07	1.09	3.20	0.784	3.99	5.08	238	15	5	14
9107	1590.356	0.07	1.04	3.21	0.801	4.01	5.05	230	12	3	10
TCA8010	1590.356	0.07	0.01	0.05	0.004	0.05	0.06	50	1633	183	1292
TCA8010	1590.356	0.08	0.01	0.05	0.000	0.05	0.06	50	1667	167	1308
TCA8010	1590.356	0.07	0.01	0.05	0.004	0.06	0.07	57	1586	229	1284
TCA8010	1590.356	0.10	0.01	0.05	0.004	0.06	0.07	57	1486	214	1203
TCA8010	1590.356	0.06	0.01	0.06	0.004	0.06	0.07	86	1486	243	1220
TCA8010	1590.356	0.02	0.02	0.06	0.004	0.07	0.09	156	1100	100	857
TCA8010	1590.356	0.07	0.01	0.05	0.004	0.05	0.06	67	1800	200	1423
TCA8010	1590.356	0.08	0.01	0.05	0.004	0.06	0.07	71	1443	157	1139

TCA8010

Mean	1590.356	0.07	0.01	0.05	0.004	0.06	0.07	74	1525	187	1216
St.Dev.	0.00	0.02	0.00	0.00	0.00	0.01	0.01	35.16	207.56	45.80	167.63

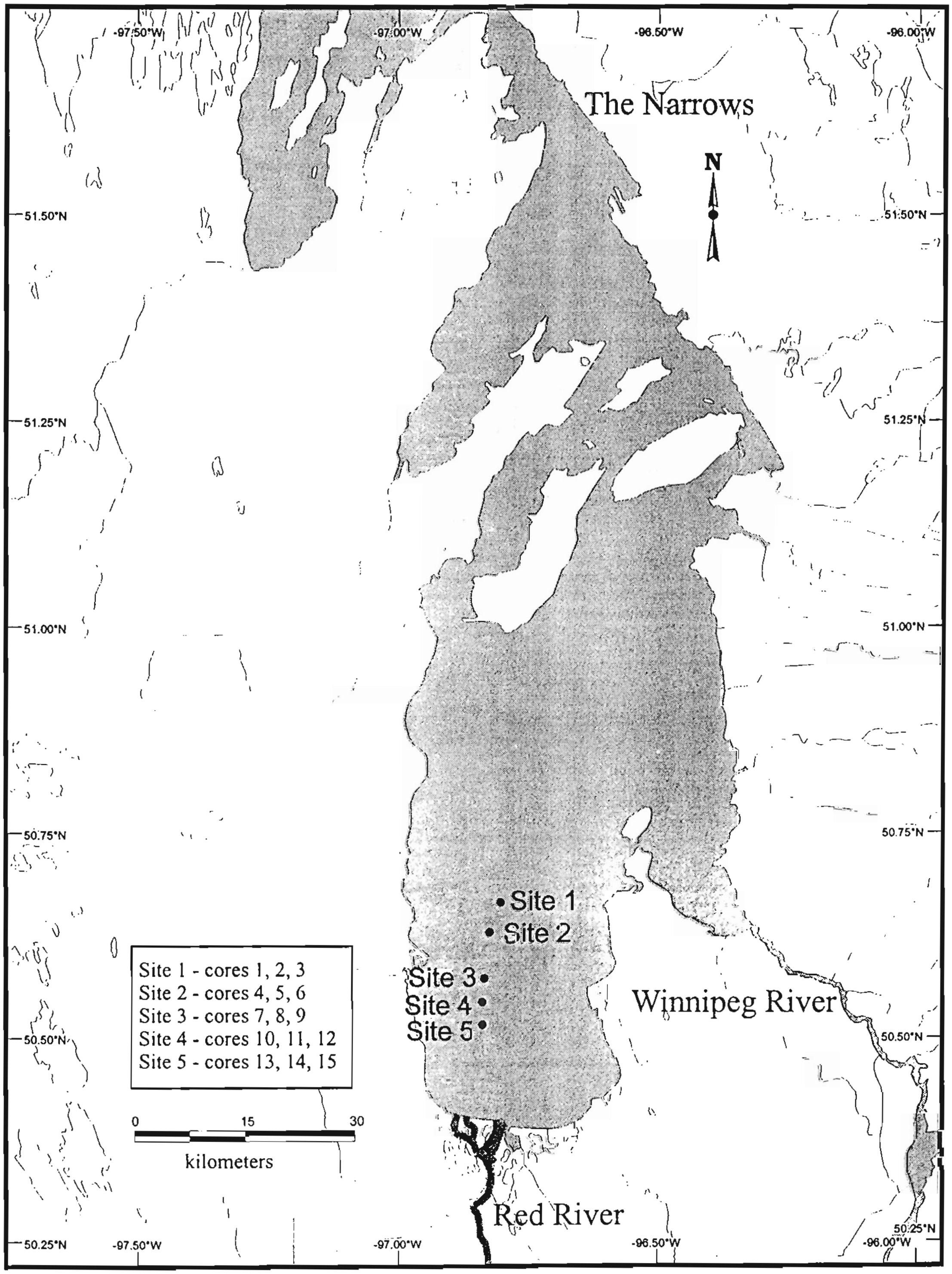


Figure 1. Map of southern Lake Winnipeg showing locations of coring sites

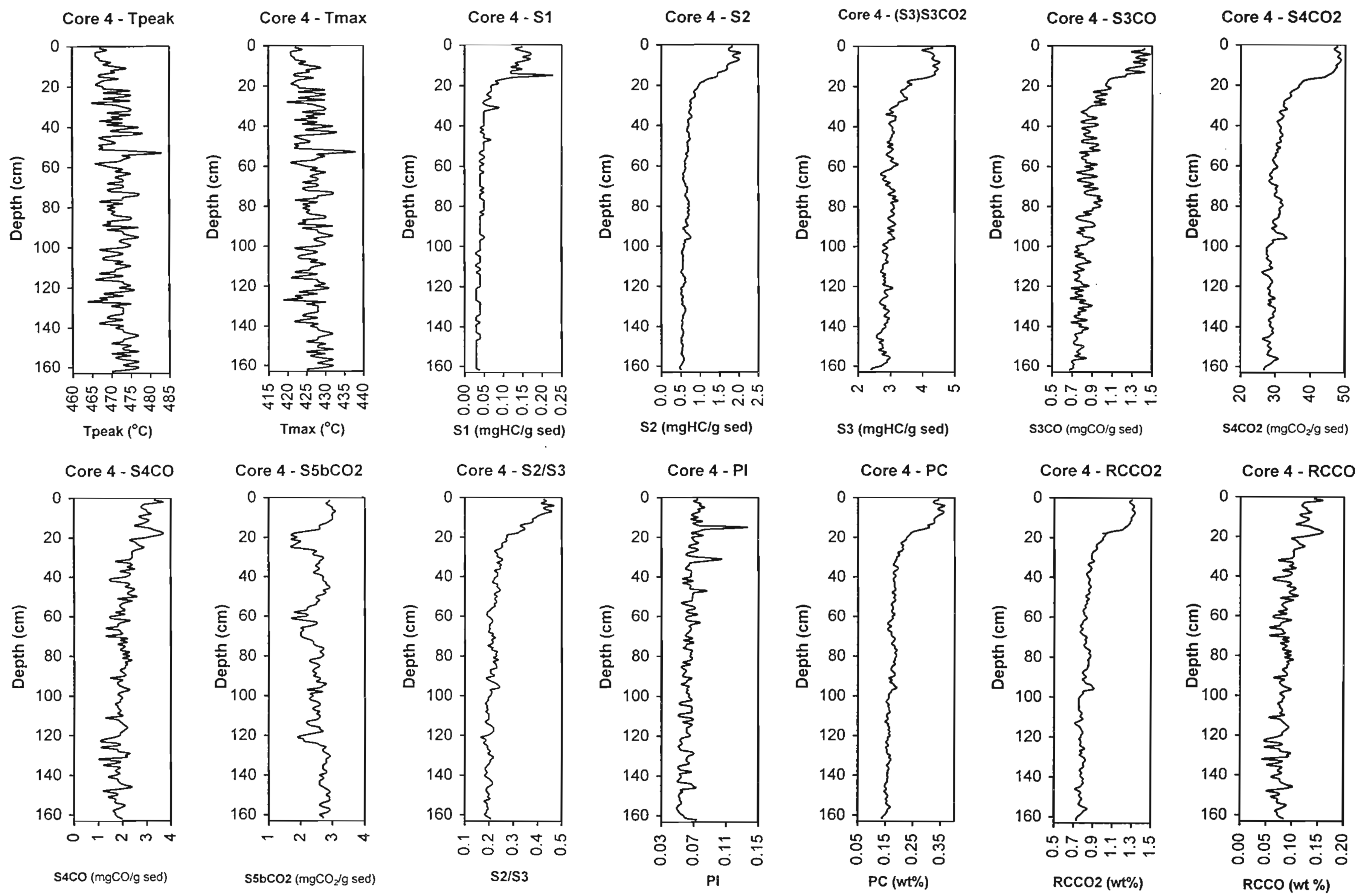


Figure 2. Down-core variations in Rock-Eval parameters for Lake Winnipeg 99-900 core 4

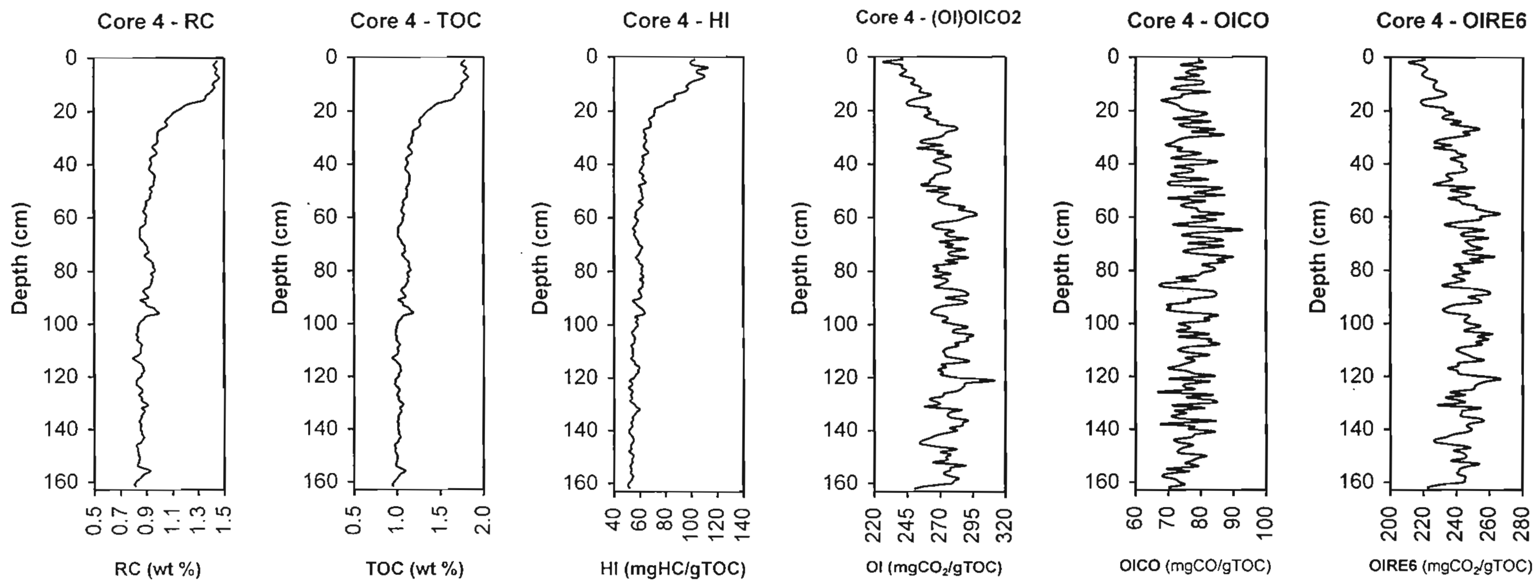


Figure 2 continued

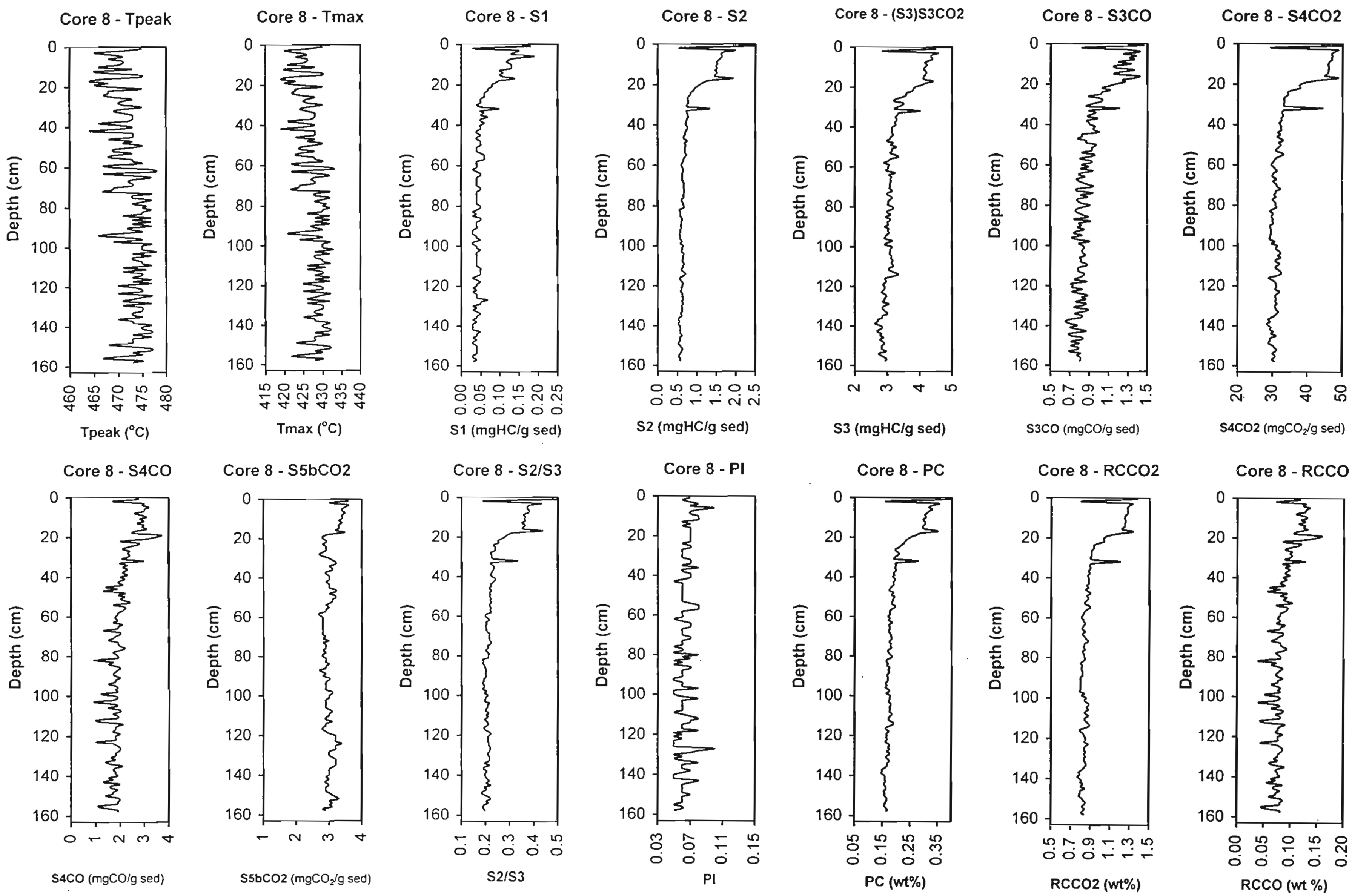


Figure 3. Down-core variations in Rock-Eval parameters for Lake Winnipeg 99-900 core 8

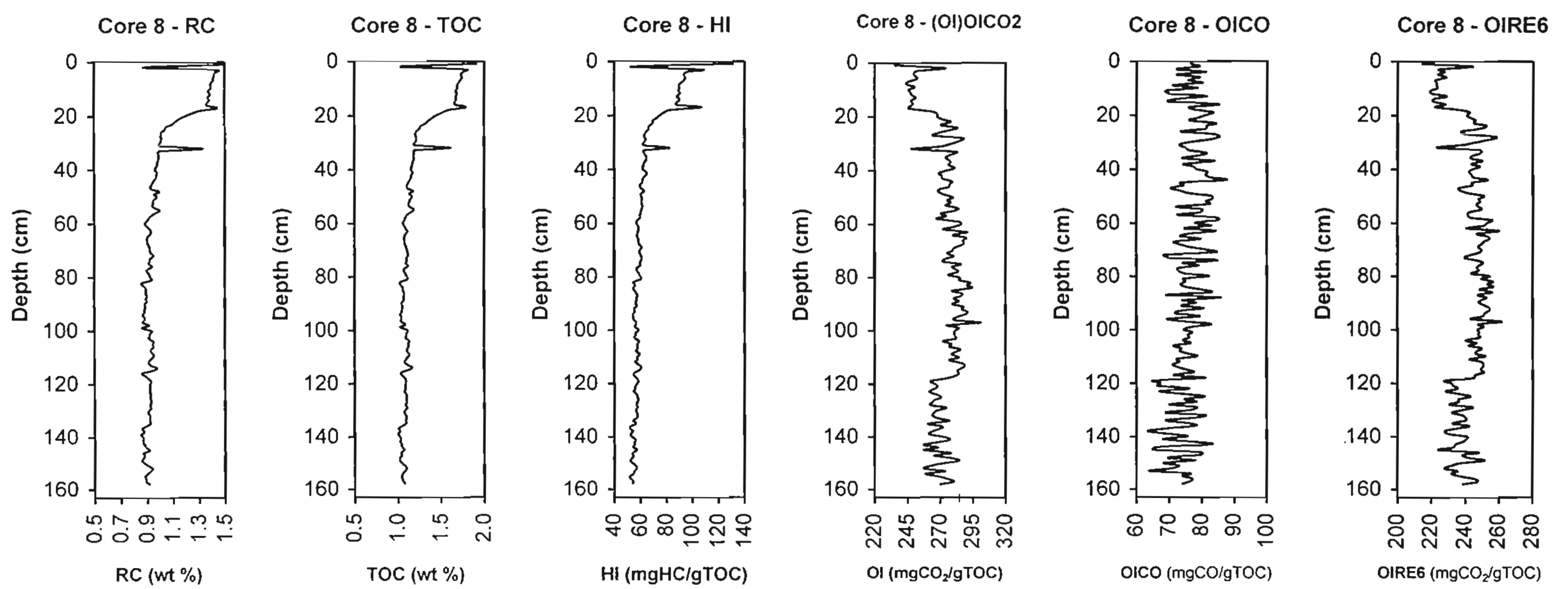


Figure 3 continued

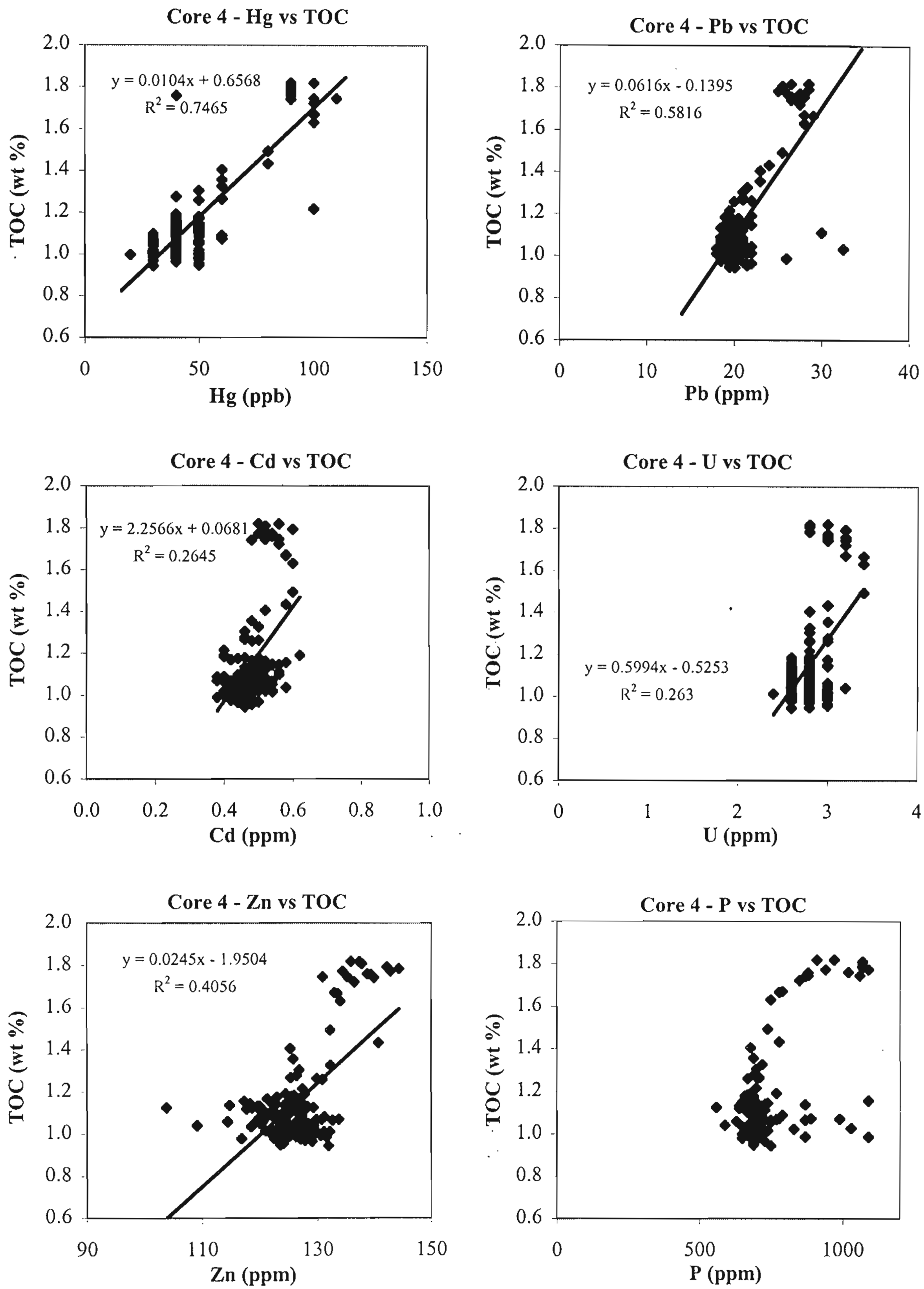
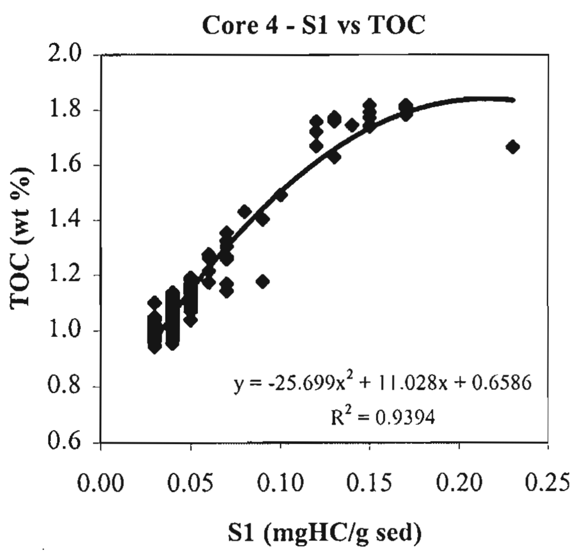


Figure 4. Cross plots of Rock-Eval parameters and elemental concentrations for Lake Winnipeg 99 - 900 core 4



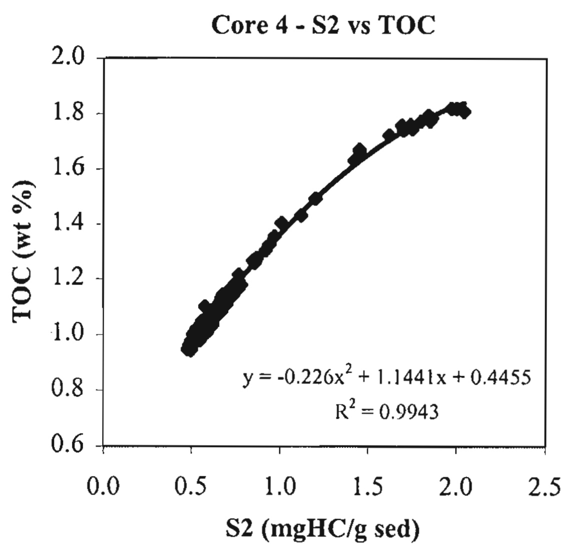


Figure 4 continued

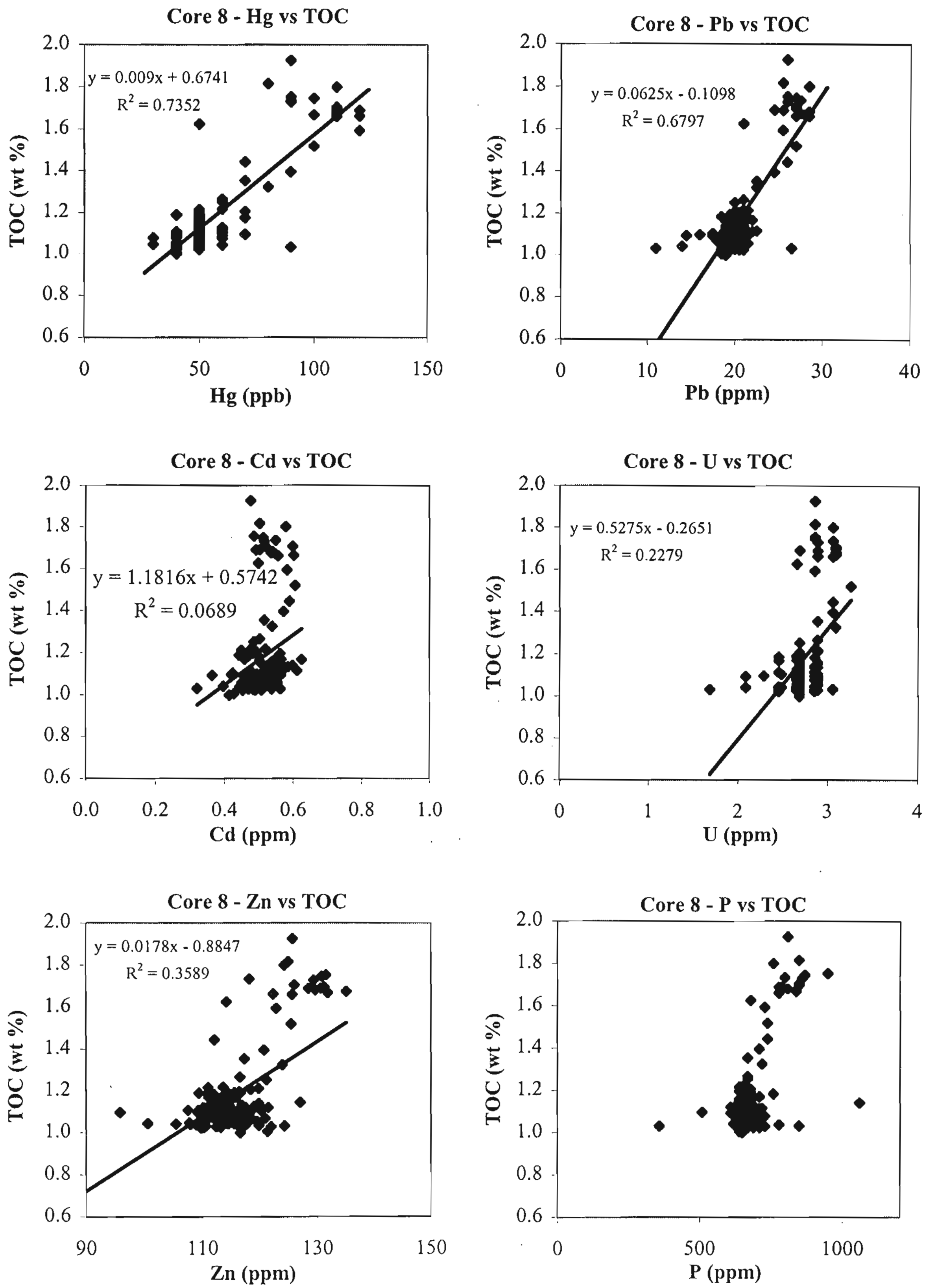


Figure 5. Cross plots of Rock-Eval parameters and elemental concentrations for Lake Winnipeg 99-900 core 8

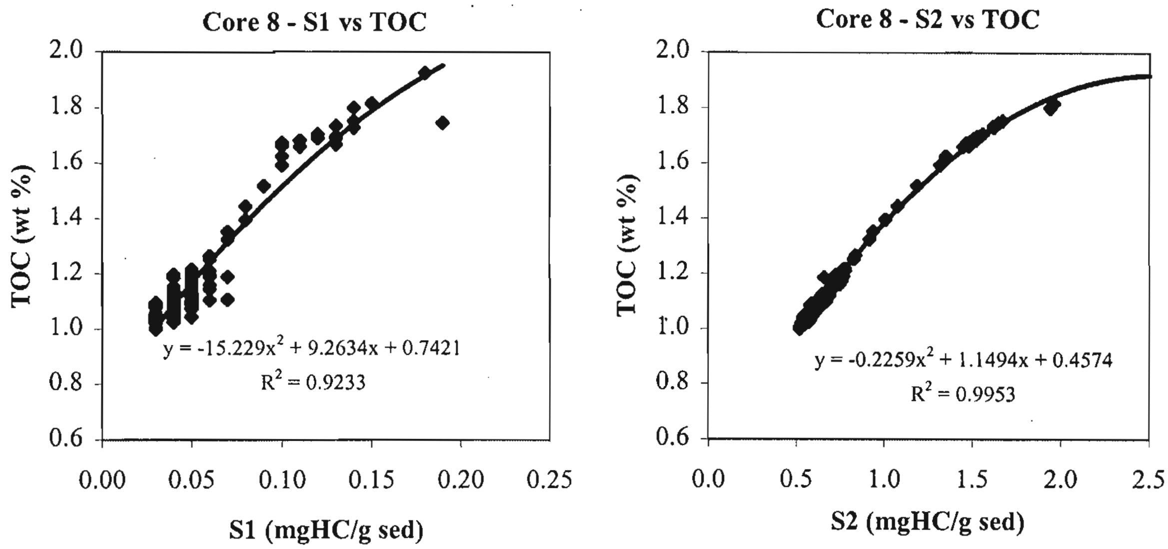


Figure 5 continued

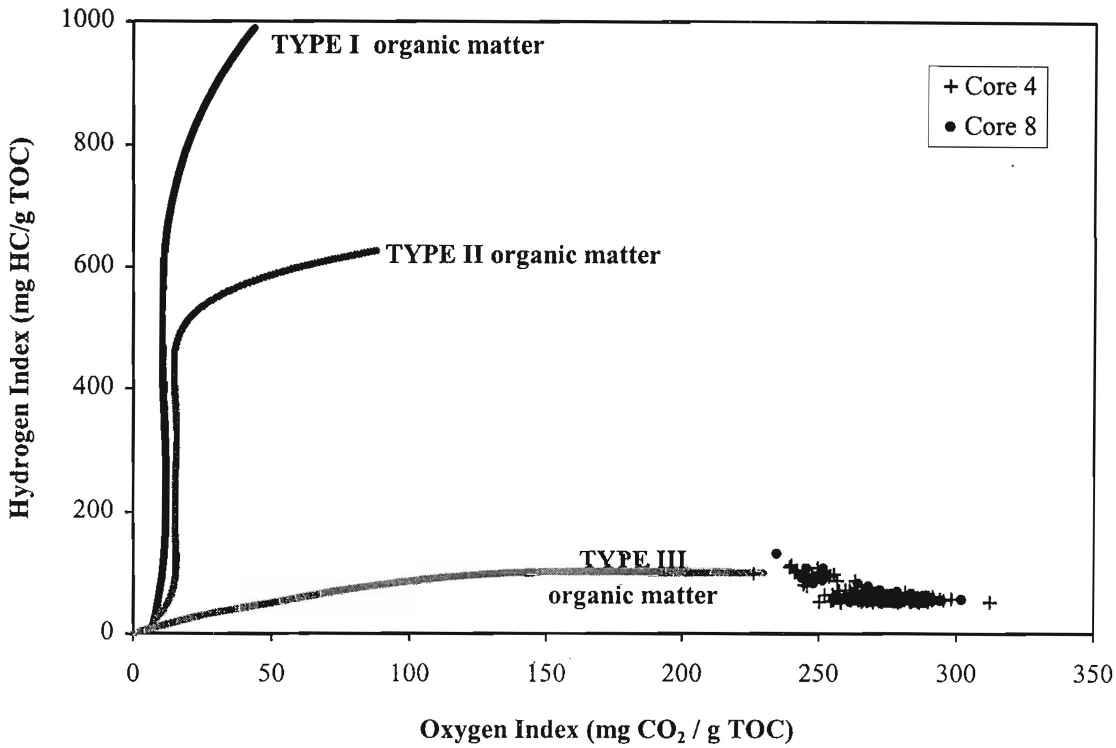


Figure 6. Rock-Eval pseudo van Krevelen plot for sedimentary organic matter from Lake Winnipeg 99-900 cores 4 and 8. Type I organic matter is typical of microbial biomass or the waxy coatings of land plants. Type II is derived from algae and Type III is typical of woody plant matter (vascular plants).

5.5 Carbon and nitrogen elemental and isotopic analyses of the non-carbonate fraction in Lake Winnipeg 99-900 core 8

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ABSTRACT

*Following the 1997 Red River flood, research addressing the history and controls on the flood hazard included analysis of sediments in Lake Winnipeg to assess flood history and drainage basin evolution. To do so, 15 cores, each about 1.5 m long, were collected from the south basin during a cruise of the Canadian Coast Guard Ship (CCGS) Namao in August 1999, designated Geological Survey of Canada (GSC) cruise 99-900.** Carbon and nitrogen elemental and isotopic analyses of one of these cores were used to test for the presence of trends and/or events in offshore sedimentation. The cored sediments are attributed approximately to the past 1100 years on the basis of radiochemistry, paleomagnetic analysis, palynology and radiocarbon dating. Organic carbon and nitrogen contents of the offshore sediments are low, together comprising less than 2 % of the total material. Carbon-nitrogen ratios and carbon isotopic compositions suggest that lacustrine organic matter in the offshore sediments is derived almost exclusively from lacustrine algae. Diagenetic alteration of organic matter is generally extensive in oxic lakes, however, this process does not appear to have significantly altered C/N_{org} ratios and $\delta^{13}C_{org}$ values of Lake Winnipeg sediments. The constancy of the carbon and nitrogen record over the past 1100 years, excluding a shift in the twentieth century, indicates that environmental conditions, such as climate, watershed dynamics and transport mechanisms, have not changed sufficiently during this time to affect these values. However, enrichment of carbon and nitrogen isotopic values at the top of the core suggests that the use of nitrogen fertilizers in the latter half of the 20th century caused increased nitrogen flux to the lake and subsequently enhanced algal productivity, which could be contributing to eutrophication of the lake. Several centimeter-scale layers of depleted $\delta^{13}C_{org}$ content were identified and could have arisen due to nutrient influxes associated with flood events. However, other processes cannot be ruled out for the formation of these layers. Although some of the layers correspond to some of the known floods of the past 200 years, further research on another core is required to corroborate the findings.

INTRODUCTION

The Red River flood of 1997 was a major disaster that drove 103,000 people from their homes. Much is being done, however, to reduce comparable damage and disruption in the future through enhanced dikes and diversions, as well as revised land use and water management practices. The design of these works requires an optimal understanding of the risk. Research therefore has addressed the nature of the largest known flood, in 1826, whether comparable large floods have occurred in recent centuries, and how geomorphic, climatic, land use, and tectonic factors may be changing the flood hazard. These issues are being addressed by examining the geomorphic processes governing evolution of the Red River, archival records of flood history, floodplain stratigraphic records, tree-ring records, changes in valley gradients, and by examining the stratigraphy of Lake Winnipeg sediments (Thorleifson et al., 1998). The coring in Lake Winnipeg, receiving basin of waters from the Red River, was designed to sample sites most likely to have recorded any influx of sediments from the Red River that may have occurred. In addition to recording gradual changes in Red River sediment transport, it was thought that flood events might be recognizable, due to unique properties allowing differentiation from other sediments in the lake, although it was unclear what attribute would best distinguish flood-related sediments. The cores therefore were thoroughly analyzed for chronology, as well as for a broad range of physical, chemical and biological properties to determine which, if any, would record a history of flooding.

Both the stable isotopic composition of carbon ($\delta^{13}C_{org}$) and carbon-nitrogen ratios (C/N_{org}) in the organic fraction have been used extensively to determine sources of organic matter in lacustrine sediments (e.g. Talbot and Lærdal, 2000; Meyers and Lallier-Vergès, 1999; Talbot and Livingstone, 1989). Despite the fact that, by the time burial of organic matter has occurred, only a few percent of the original organic matter remains unaltered by degradation and remineralization, C/N_{org} ratios and $\delta^{13}C_{org}$ values tend to retain their character and, as a result, can be used to identify sources of organic matter (Meyers, 1994). Kendall et al. (2001) have linked $\delta^{13}C_{org}$ depletions in riverine DIC to algal blooms resulting from floods, thus the potential for recognition of floods in lacustrine sediments derived from

* Italicized text is repeated in each chapter

rivers exists. These analyses therefore are useful for providing information on paleoenvironmental changes, such as those in watershed dynamics, lake productivity, and climate. The stable isotopic composition of nitrogen ($\delta^{15}N$), although not widely studied, has been used in a few studies to provide information on sources of organic matter in lacustrine sediments and on paleoenvironmental conditions (e.g. Pang and Nriagu, 1976; Pang and Nriagu, 1977; Talbot and Johannessen, 1992). The study of $\delta^{15}N$ compositions in lake waters has also been used to fingerprint sources of contamination from artificial and natural fertilizers as well as sewage effluent. Interpretation of $\delta^{15}N$ results is, however, complicated by a number of isotopic and other effects.

In order to examine properties of the sedimentary organic matter (OM) in Lake Winnipeg, including type and proportion of allochthonous versus autochthonous OM, the sediments were analyzed for carbon and nitrogen elemental and isotopic compositions. It was thought that carbon and nitrogen elemental and isotopic analyses may preserve a record of the rapid influx and deposition of higher land plant debris that might be expected to accompany floods. Subsequently, it was recognized that an understanding of the relative dominance of algae in the lake would be gained, because enhanced algal productivity, often the result of enhanced nutrient influx from anthropogenic sources such as fertilizers, animal wastes, septic system effluents and phosphate detergents, can lead to eutrophication of lake waters.

LAKE WINNIPEG

Lake Winnipeg, located in central North America, is the eleventh largest lake in the world, having an area of 24,000 km^2 (Hutchinson, 1975). The lake straddles the contact between Paleozoic carbonate rocks to the west and Precambrian igneous and metamorphic rocks of the Canadian Shield to the east. A smaller south basin, approximately 90 km by 40 km, is separated from a north basin, approximately 240 km by 100 km, by a narrow passage known as The Narrows. The glacially-scoured depression in the rocks underlying the lake, with a depth of 50-100 m, is largely filled with fine-grained glacial Lake Agassiz sediments, overlain by up to 15 m of post-glacial Lake Winnipeg sediments (Todd and Lewis, 1996). The bathymetry of the lake is shallow and the bottom is flat, with depths averaging 9 m in the south basin and 16 m in the north basin. The lake has a catchment area extending from the Rocky Mountains to very near Lake Superior, including the basins of the Winnipeg, Saskatchewan, Red, Dauphin and numerous smaller rivers. Outflow from the lake is north to Hudson Bay, through the Nelson River. Post-glacial uplift has caused the north end of the basin to rise relative to the south, causing a gradual rise of lake levels that continues at present (Lewis et al., 2000). The mean annual temperature of the region, recorded at Gimli, is +1.4°C, although the continental climate of the region ranges from hot summers to very cold winters. The mean annual precipitation is 50.8 cm. The lake is ice free from early May to late November (Ice Thickness Climatology, 1992) and ice cover from November to May is consistently thick and continuous. The lake waters are poorly stratified to unstratified and during the summer months water temperatures range from +17°C in the north basin to +19.5°C in the south basin (Todd, 1996), hence bottom sediment temperatures are equally warm in mid-summer. The lake supports a commercial fishery, it is a major destination for recreation, and lake levels are regulated to optimize hydroelectric power generation on the Nelson River.

SAMPLING AND ANALYTICAL METHODS

Selection of five sampling sites in the south basin of Lake Winnipeg was based on proximity to the Red River mouth and on the absence of ice scour on sidescan sonar records previously obtained in 1994 on the 94-900 Namao cruise (Lewis et al., this volume) (Figure 1). Site 5 was the southernmost point on the north-south survey line that lacked ice scour. Sampling was conducted in calm weather on August 24, 1999 from the CCGS Namao. Three cores were obtained at each of the five sites using a gravity corer consisting of a 100 kg weightstand over a 2 m steel pipe with a 10 cm diameter plastic liner tube. The length of the cores ranged from 107 cm to 170 cm. The cores were sealed, labelled and transported to Gimli, Manitoba on August 29, where they were refrigerated, and subsequently transported via refrigerated truck to the GSC Atlantic core storage facility in Dartmouth, N.S. A monitoring device attached to the core bundle indicated that the sediments did not exceed a temperature of 19°C at any time during transport. Paleomagnetic and physical property data, determined at the laboratory of Professor J.W. King at the University of Rhode Island, provided information used to select cores that would be representative of the offshore sediments (King et al., this volume). Paleomagnetic profiles indicated more rapid accumulation of sediments at the more northerly sites and hence a higher resolution for examining environmental change. Based on these observations, core 8 (site 3), core 4 (site 2) and core 3 (site 1) were selected as the primary records for detailed study.

Core 8 was selected for carbon and nitrogen elemental and isotopic analyses, which included determination of the percentages of carbon (% C_{org}) of the organic fraction and nitrogen (% N), the carbon-nitrogen ratio (C/N_{org}) and the stable isotopic compositions of carbon ($\delta^{13}C_{org}$) and nitrogen ($\delta^{15}N$) in the sediments.

A total of 158 samples from core 8 were sampled at 1-cm increments at GSC facilities in Dartmouth, and prepared for several procedures at the Freshwater Institute in Winnipeg. At the University of Winnipeg the samples were treated with 10 % HCl to remove carbonate, rinsed with distilled water, and freeze-dried. Removal of carbonate allowed for the determination of carbon elemental and isotopic compositions of the organic matter only. Nitrogen elemental and isotopic compositions include both organic and inorganic fractions.

Carbon and nitrogen content and carbon and nitrogen isotopic compositions were determined on the prepared material by continuous flow - isotope ratio mass spectrometry at the Isotope Science Laboratory (ISL) at the University of Calgary using a Finnigan Mat TracerMat with NA 1500 EA coupled to a delta plus XL. Carbon and nitrogen contents were expressed as ratios of carbon to nitrogen weights (C/N_{org}). Carbon and nitrogen isotope results were expressed using standard delta (δ) notation in units of per mil (‰). The delta values of carbon and nitrogen represent deviations from a standard, such that $\delta_{sample} = [(R_{sample}/R_{standard})-1]*10^3$ where R is the $^{13}C/^{12}C$ or $^{15}N/^{14}N$ ratio in the sample and the standard. The standards used for carbon and nitrogen isotopic analyses are V-Peedee Belemnite (VPDB) and AIR, respectively.

Analytical precision, determined from the analysis of duplicate samples, was ± 0.14 ‰ for $\delta^{13}C_{org}$ and ± 0.10 ‰ for $\delta^{15}N$. Accuracy was obtained through the analysis of laboratory standards used for calibration of results.

RESULTS

Values for $\delta^{13}C_{org}$ were normalized to account for the historic depletion of $\delta^{13}C$ in atmospheric CO_2 caused by the burning of fossil fuels (Keeling et al., 1989). Normalization eliminates such problems as underestimating productivity in recently deposited sediments (Schelske and Hodell, 1995). A correction term for each dated sediment slice was calculated from $\delta^{13}C = (-4{,}577.8) + (7.3430t) - (3.9213 \times 10^{-3}t^2) + (6.9812 \times 10^{-7}t^3)$, where t is the time in years AD (Schelske and Hodell, 1995). Ages of the sediments were obtained from the composite geochronological model by Wilkinson and Simpson (this volume). The correction term was subtracted from measured $\delta^{13}C_{org}$ values for each slice to obtain normalized values.

Values for % C_{org}, % N, C/N_{org}, $\delta^{15}N$ and $\delta^{13}C_{org}$ (original and normalized values) of the sedimentary OM are presented in Table 1. The table includes the depth in cm below the top of the core and the values obtained for each parameter. The percentage of organic carbon and organic nitrogen present in the sediments average 1.22 % and 0.14 %, respectively. Percent organic carbon values are consistent with total organic carbon (TOC) values obtained from Rock-Eval analysis (Snowdon and Simpson, this volume). Values for C/N_{org} average 4.3, while those for $\delta^{15}N$ and $\delta^{13}C_{org}$ average 3.8 ‰ and –26.2 ‰, respectively. Standard deviations of results for each parameter are also given in Table 1. Down-core variations in % C_{org}, % N, C/N_{org}, $\delta^{15}N$ and $\delta^{13}C_{org}$ (original and normalized values) are shown in Figure 2.

Variations with depth

Both % C_{org} and % N values remain relatively constant below a depth of 30 cm, then show a gradual increase between 30 and 20 cm, followed by a sharper increase between 20 to 15 cm. Above 15 cm, values level off. Minimum and maximum values for % C_{org} are 0.7 and 2.0, respectively, while those for N are 0.10 and 0.24, respectively.

Although C/N_{org} ratios show a wider range of values with depth than % C and % N values, with a minimum value of 2.3 and a maximum value of 7.1, the values are fairly constant with depth. However, there does appear to be a very subtle downcore increase in values, with values for the top 20 cm being, on average, lower than those below this depth. The spiky nature of the C/N_{org} ratios with depth may be an analytical effect.

Values for $\delta^{15}N$ are fairly constant with depth below 20 cm, but rise above this depth, showing an average 2.3 ‰ enrichment.

Values for $\delta^{13}C_{org}$ show slight downcore enrichment below 20 cm, but show an average 0.5 ‰ enrichment above 15 cm. Depletions in $\delta^{13}C_{org}$ values coincidently occur with increases in % C content at 2 cm, 16-17 cm, 27-31 cm, 32-33 cm, 36-38 cm, 41-44 cm, 47-48 cm, 53-57 cm, 63-65 cm, 72-76 cm, 79-81 cm, 87-91 cm, 105-108 cm, 112-113 cm, 127-129 cm and 156 cm (Figure 3). Between 15 and 20 cm the values are variable. Enrichment of $\delta^{15}N$ and $\delta^{13}C_{org}$ values observed at the tops of the cores is greater than the analytical error.

DISCUSSION

Organic matter in lakes

Organic matter in lakes is derived from both autochthonous (in place) and allochthonous (transported) sources. The relative proportion of autochthonous versus allochthonous organic matter is of interest, as this ratio is controlled by lake morphology, watershed topography, climatic conditions and the productivity of the plants (Meyers and Lallier-Vergès, 1999). Autochthonous organic matter includes phytoplankton, algae (aquatic plant) and macrophytes (vascular aquatic plants), while allochthonous organic matter is of terrestrial origin and includes fresh plant material and soil organic matter, transported to lakes by rivers, runoff and wind. Autochthonous organic matter is predominantly aliphatic, rich in nitrogen and composed largely of low molecular weight material, that may be readily decomposed and recycled to CO_2, ammonia, nitrate and phosphate. Phytoplankton and algae are nonvascular, and contain little or no carbon-rich cellulose. Allochthonous fractions tend to be rich in aromatics, low in nitrogen, of high molecular weight and quite refractory. Trees, shrubs and grasses, which are most commonly terrestrial, are vascular, and contain a large proportion of cellulose. The varied characteristics of authochthonous and allochthonous organic matter allows for recognition of the contributions of each to the lacustrine sedimentary record.

A number of processes, occurring both prior to and following sedimentation, affect the preservation of organic matter in lacustrine environments. In fact, up to 60-70 % of the organic matter in young lacustrine sediments consists of humic material, which is derived from diagenetic processes, in particular, microbial reworking (Ishiwatari, 1985). Processes of alteration of organic matter have been discussed by Meyers and Ishiwatari (1993), who found that within the water column, the most prevalent form of organic matter alteration is biochemical oxidation of organic matter, accomplished by microbes, which recycle (mineralize) the most easily degraded forms of organic matter. Terrestrial organic matter was found to be less easily degraded by microbes (more refractory) than planktonic organic matter. Eadie et al. (1984), for example, showed that 94 % of the primary aquatic organic matter in Lake Michigan is recycled before reaching the lake bottom.

C/N_{org} and $\delta^{13}C_{org}$ signatures of primary (source) organic matter

C/N_{org} signatures

The abundance of cellulose in plant sources of organic matter controls the C/N_{org} ratio of these plants. Algae and vascular plants each have characteristic C/N_{org} ratios, and as such provide a means of distinguishing between lacustrine organic matter of terrestrial versus aquatic provenance. Plankton, which have abundant nitrogen and are lacking in C-rich cellulose, are characterized by low C/N_{org} ratios, between 4 and 10, while vascular terrestrial plants, which contain cellulose, are characterized by C/N_{org} ratios generally greater than 20 (Meyers, 1994). Values between 10 and 20 indicate a mixed source of terrestrial and aquatic material.

Small changes in C/N_{org} ratios have been observed in lacustrine sediments during early diagenesis. For example, settling particles in Lake Michigan have C/N_{org} ratios of about 9, while re-suspended bottom sediments have values of about 8 (Meyers et al., 1984). However, changes in C/N_{org} values resulting from early diagenesis are small and do not significantly alter the primary signature of the organic matter. Burial of organic matter in lake-bottom sediments prevents further alteration of C/N_{org} values.

$\delta^{13}C_{org}$ signatures

The $\delta^{13}C_{org}$ value of plants varies depending on the mechanism the plant uses to incorporate carbon from atmospheric carbon dioxide. During photosynthesis, the carbon that is incorporated into plant tissue is enriched in ^{12}C and depleted in ^{13}C relative to atmospheric carbon dioxide ($\delta^{13}C$ = -7 ‰). Most photosynthetic plants incorporate carbon into organic matter using the C_3 Calvin pathway, which causes a $\delta^{13}C$ shift of –20 ‰ from atmospheric carbon, resulting in organic matter with an average $\delta^{13}C$ value of –27 ‰. Other photosynthetic plants incorporate carbon using the C_4 Hatch-Slack pathway, which causes a $\delta^{13}C$ shift of only –7 ‰, resulting in organic matter with an average $\delta^{13}C$ value of –14 ‰ (O'Leary, 1988). Most terrestrial plants, such as trees, shrubs and herbs utilize the C_3 pathway, while desert plants, salt marsh plants and tropical grasses are among those that use the C_4 pathway.

Aquatic plants (phytoplankton and macrophytes) predominately synthesize organic matter via the C_3 pathway. Phytoplankton, thought to be the major autochthonous contributor to offshore south basin sediments, preferentially incorporate ^{12}C from dissolved inorganic carbon (DIC), which is in equilibrium with atmospheric carbon. The $\delta^{13}C$ composition of the DIC reservoir is controlled dominantly by seasonal changes in photosynthesis and respiration, but also by lake temperature, the extent of equilibrium between atmospheric CO_2 and lake water, and the influx of CO_2 from both the decomposition of ^{13}C-depleted organic matter and the chemical weathering of ^{13}C-enriched carbonate rocks in the catchment (Stuiver, 1975; Mckenzie, 1985; Buchardt and Fritz, 1980; Hakansson, 1985; Talbot and Johannessen, 1992). Enhanced productivity over time could result in ^{13}C enrichment of the lake's DIC reservoir, which would cause progressive enrichment of the ^{13}C composition of the autochthonous organic matter (Schelske and Hodell, 1991). Typical $\delta^{13}C$ values for the DIC reservoir range from –15 to –6 ‰ (Boutton, 1991). Incorporation of carbon from the lake's DIC reservoir into phytoplankton causes a $\delta^{13}C$ shift of 20 ‰ from the reservoir's value, resulting in $\delta^{13}C$ compositions of –42 to –26 ‰ (averaging –27 ‰) for the phytoplankton (Boutton, 1991).

In most cases, $\delta^{13}C_{org}$ values for algal organic matter are indistinguishable from those of terrestrial C_3 plants. However, situations where carbon isotopic distinctions between autochthonous and allochthonous organic matter do arise. For example, an increase in the relative contribution of autochthonous versus allochthonous organic matter has resulted in distinct enrichments in $\delta^{13}C_{org}$ that revealed periods of enhanced phytoplankton productivity (Aravena et al., 1992). In another study, seasonal variations in the $\delta^{13}C_{org}$ composition of organic carbon in the St. Lawrence River were shown to correspond with changes in river discharge, and hence, the supply of allochthonous organic matter (Tan, 1987). During three consecutive sampling years, the $\delta^{13}C_{org}$ values were more depleted (-27 ‰) from April to June and more enriched (-24 ‰) from August to October. The more depleted $\delta^{13}C_{org}$ values were found to be associated with the high spring discharge, while the more enriched values were associated with the low fall discharge. This effect is to be attributed to the more dominant contribution of allochthonous terrestrial organic carbon, which in this environment has a more depleted signature than autochthonous material, during periods of high discharge. Hence, more depleted $\delta^{13}C_{org}$ values may, in some instances, be indicative of enhanced recharge.

Typically, diagenesis of sedimentary organic matter in lakes causes negligible or minor alteration of $\delta^{13}C_{org}$ values, insufficient to mask the signature of the source organic matter. For example, $\delta^{13}C_{org}$ values of organic matter in modern lake-bottom sediments and 3500-year old sediments in Lake Michigan were similar (Rea et al., 1980). However, shifts of up to 4 ‰ in the $\delta^{13}C_{org}$ values of less common plants, such as the C_4 marsh grass *Spartina alterniflora*, have been observed during early diagenesis (Benner et al., 1987).

The occurrence of slight, gradual down-core enrichment in $\delta^{13}C_{org}$ and C/N_{org} compositions in the Lake Winnipeg sediments, below a depth of 30 cm, may be the result of diagenetic alteration. The slight enrichment observed here is not significant enough to mask the original signature of the source organic matter. Trends of this nature were not observable in % C_{org}, % N or $\delta^{15}N$ values.

C/N_{org} versus $\delta^{13}C_{org}$ plots

C/N_{org} and $\delta^{13}C_{org}$ data have been used to determine the source(s) of organic matter in lacustrine sediments, as unique fields of C/N_{org}-$\delta^{13}C_{org}$ composition are evident for C_3 land plants, C_4 land plants and lacustrine algae (Meyers, 1994; Meyers and Lallier Vergès, 1999) (Figure 4). Individual datasets may plot within one of the specified fields, although some may plot between two or more source fields, which indicates that the organic matter was derived from more than one source. In cases where there are multiple sources, the relative proportion of each source can be delineated.

The low (<10) C/N_{org} values and the position of the sediments in the lacustrine algae field of the C/N_{org} versus $\delta^{13}C_{org}$ diagram indicate that OM from offshore Lake Winnipeg is dominated by lacustrine algae (Figure 4). Inorganic sediments from shoreline, river or aeolian processes are not effective in transporting much organic material. In addition, the offshore Lake Winnipeg sediments analyzed here have low organic matter contents, together comprising less than 2 % of the total material.

Values for C/N_{org} and $\delta^{13}C_{org}$ are relatively steady with time below a depth of 30 cm, indicating that lacustrine algae have dominated offshore OM sedimentation for much of the past 1100 years. This suggests a lack of changes in climate, watershed dynamics or transport mechanism of inorganic material during this interval capable of impacting this aspect of the sediments.

Sources of nitrogen using $\delta^{15}N$ signatures

In order to accurately determine the proportions of various nitrogen sources, organic and inorganic, to the sediments of Lake Winnipeg, the nitrogen isotopic compositions of plankton in the lake, soil in the watershed, fertilizers used on the land, and any other major sources of contamination would have to be characterized. Given that direct measurements of these nitrogen reservoirs have not been made, their compositions can only be estimated from average values or ones obtained from similar environments. Lake Winnipeg plankton is assumed to have a nitrogen isotope composition close to that of coastal marine plankton (+ 6 ‰; Gearing, 1988). Natural soils are assumed to have a composition between + 2 ‰ and + 5 ‰ (Broadbent et al., 1980), but are likely closer to the lower end due to the prevalence of soil cultivation in the region. A compilation of fertilizer materials sold in Manitoba in 2000 shows that urea (mean value + 0.18 ‰) and anhydrous ammonia (mean between 0 and 1 ‰) comprise the majority of sales of nitrogen fertilizers in the province, at 36 % and 32 %, respectively (Canadian Fertilizer Institute). Given that these two fertilizer types are sold in approximately equal proportions, and that application rates of sold products are at least 95 %, the $\delta^{15}N$ composition of fertilizer materials applied in the province is assumed to be between 0 and 1 ‰ (Hubner, 1986).

In the Lake Winnipeg core, background (pre-1930's) $\delta^{15}N$ compositions are constant and average 3.5 ‰, whereas post-1930's compositions average 5.7 ‰. Background levels in Lake Winnipeg sediments are very similar to values for sediments derived from terrestrial material in lakes Superior and Ontario (3.7 ‰) (Pang and Nriagu, 1976; Pang and Nriagu, 1977) and these values fall within the range of those expected for soil organic matter. Therefore, pre-1930's $\delta^{15}N$ compositions likely result from the normal transfer of soil nitrogen to the lake, undisrupted by modern contributions of fertilizers and sewage, or by significant changes in the depositional environment during the past 1000 years. The contribution of plankton to the nitrogen content of the pre-1930's sedimentary record is apparently minimal.

Evidence for nutrient influx and enhanced productivity

% carbon$_{org}$

The greater organic carbon content in the top 20 cm of the Lake Winnipeg core may relate to an increase in the proportion of allochthonous organic matter discharging into the south basin of Lake Winnipeg. This may relate to changes in climate and/or the level of agricultural activity. Historically, the 19th century is recorded as a period of greater precipitation with major floods (Blair and Rannie, 1994). During the late 19th and early 20th centuries the Red River basin experienced a period of accelerated land clearance for agricultural purposes. Increases in basin runoff and Red River discharge since the 18th century may have washed organic material into the river, causing increases in organic carbon entering the lake and hence, the lake-bottom sediments. Additionally, higher river discharge associated with the above mentioned increased precipitation and flood periods could have caused an increase in the amount of suspended particles in the lake waters, perhaps causing a reduction in photosynthetic productivity. This could have the effect of increasing the relative proportion of allochthonous organic matter.

% nitrogen

Increases in the organic nitrogen content in the top 30 cm most likely relate to modern agricultural land use practices (summer fallow and use of fertilizers). The practice of ploughing the land and leaving it unsown results in more rapid removal of nutrients from the soil during precipitation events and the transfer of nutrients into the waterways. Large, single doses of fertilizers are commonly applied to crops, which results in excess nutrients to wash into the waterways.

C/N$_{org}$ *indicators*

In addition to providing information regarding the source of organic matter in lake sediments, C/N_{org} ratios may be useful for determining the productivity of phytoplankton in the past, thus providing information on how lake productivity has evolved with time. Given the dominant lacustrine algae signature of the Lake Winnipeg sediments throughout the past 1100 years, and the apparent lack of transport of terrestrial organic matter to the offshore environment, shifts in the relative proportions of terrestrial versus aquatic organic matter are absent and therefore could not be used to deduce information on eutrophication. However, slight shifts in C/N_{org} values to lower values in the upper 20 cm of the core could represent enhanced dominance of lacustrine algae. The fact that C/N_{org} values were consistently less than 10 and lack significant trends indicates that phytoplankton growth was not limited by nitrogen supply (Hecky et al., 1993). Recent research on phytoplankton nutrient status in Lake Winnipeg (Hendzel et al., 2002) has shown that phytoplankton growth is not limited by phosphorus or nitrogen availability, but that light availability is the most important control on productivity. This was found to be particularly true for the south basin, in which greater turbidity limits light penetration.

$\delta^{13}C_{org}$ *indicators*

The stable isotopic composition of organic carbon in lake-bottom sediments can be used as a proxy for paleoproductivity in lakes (e.g. Schelske and Hodell, 1991; Schelske and Hodell, 1995). A direct correlation has been reported between total phosphorus (TP) loading, the dominant control on lacustrine productivity, and $\delta^{13}C_{org}$ values for organic matter in the sediments of large, deep lakes. $\delta^{13}C_{org}$ results have been used to show that nutrient loading in both Lake Ontario and Lake Erie first increased in the late 1800's, increased sharply in the 1940's and 1950's and decreased after the mid 1970's.

Enrichment of $\delta^{13}C_{org}$ values in the Lake Winnipeg core above 15 cm suggests an increased nutrient input and the corresponding enhanced lake productivity. The maximum enrichment of 0.5 ‰ is significantly less than the 1.4 ‰ enrichment observed for Lake Erie (Schelske and Hodell, 1995), suggesting that eutrophication has not been as significant in Lake Winnipeg. For Lake Winnipeg, changes in $\delta^{13}C_{org}$ values suggests that algal productivity did not begin to increase in the late 1950's and peak levels were not reached until very recently, in the late 1990's.

$\delta^{15}N$ *indicators*

Studies have linked increases in $\delta^{15}N$ compositions in lakes and seas to increases in the anthropogenic nutrient load of the water body (Talbot and Lærdal, 2000; Voss et al., 2000). This causal relationship was established by ruling out other potential causes of $\delta^{15}N$ increases, in the case of Talbot and Laerdal (2000), and by correlating the degree of up-core increases in $\delta^{15}N$ with increases in nutrient load, in the case of Voss et al. (2000). Another study (Lake et al., 2001) has used the positive relationship between $\delta^{15}N$ compositions in fish, mussels and sediments in a lacustrine environment with DIN concentrations in the water to indicate that $\delta^{15}N$ values are a valid descriptor of eutrophication at sites with low DIN concentrations.

Interpretation of the stable isotopic composition of nitrogen is complicated, being governed by processes of nitrogen cycling that may involve multiple species of dissolved inorganic nitrogen (DIN) of varying oxidation states (Talbot and Lærdal, 2000). The major processes affecting nitrogen isotopic compositions are fixation (N_2 converted to other forms by bacteria), assimilation (incorporation of N into living organisms), ammonification (production of ammonium from soil organic matter), nitrification (multi-step oxidation process by organisms to derive energy), volatilisation (loss of ammonia gas from soils to the atmosphere), and denitrification (chemical or biologically mediated reduction of nitrate to N_2), each of which impart an isotopic fractionation (Kendall, 1998). The isotopic composition of nitrogen fixed by organisms is controlled by the initial composition of the DIN source and the metabolic pathway used for nitrogen fixation. Nitrogen may be assimilated from atmospheric nitrogen, nitrate, nitrite, or ammonium, each of which undergoes varying degrees of isotopic fractionation during assimilation. Complications arise when various organisms in an environment assimilate nitrogen from different sources, some of which have not been adequately characterized. Further complications arise when nitrogen is present in limiting concentrations. In such cases, the composition of the residual DIN reservoir gradually changes during progressive nitrogen assimilation, producing a complementary change in OM nitrogen isotope compositions (e.g. Cifuentes et al., 1989; Talbot and Lærdal, 2000).

Despite the complications, stable isotopes of nitrogen have been used to distinguish amongst different sources of nitrate entering a water body (e.g. Aravena et al., 1993; Lake et al., 2001). This application is most useful when supplemented by hydrologic and chemical data, such as pH and dissolved oxygen content (Kendall, 1998). The nitrogen isotopic composition of sources and the effect of fractionating processes determine the isotopic composition of the water body. In order to determine proportions, or even qualitative estimates, of the various sources to the resulting water body, all sources must be adequately characterized and fractionation processes understood.

Further complications arise during incorporation of nitrogen-bearing materials in the water column into lake-bottom sediments. The few investigations of nitrogen isotopes in lacustrine sediments reveal that source information is retained. For example, Pang and Nriagu (1976, 1977) showed that lacustrine sediments in lakes Superior and Ontario, had lighter $\delta^{15}N$ values (+ 3.7 ‰) for areas receiving dominantly terrestrial material, whereas heavier values were observed in areas where aquatic matter dominated (+ 4.9 ‰). These values cannot be directly applied to other areas, as compositions of terrestrially derived material and dissolved species in the lake may vary substantially among sites. Diagenetic degradation causing alteration of primary $\delta^{15}N$ values occurs predominantly in the water column prior to sedimentation and causes shifts of –1 to –2 ‰ (Meyers and Eadie, 1993). Other studies have noted far greater nitrogen isotope shifts resulting from changes in one or more of the DIN reservoirs (Meyers and Ishiwatari, 1993).

Dominant sources of nitrogen to lakes include aquatic vegetation, soil organic nitrogen derived from terrestrial vegetation, commercial fertilizers and animal and human wastes. The nitrogen isotopic composition of plankton averages 6 ‰ in a coastal marine settings (Gearing, 1988), but has been poorly characterized in freshwater settings. Much of the terrestrially-derived material is washed into lakes by precipitation, which is poorly characterized due to difficulty in analysing such dilute waters and the wide range of values observed in precipitation. Nitrate (major component of DIN), which is more mobile in soils than ammonium and leaches readily from soils, and DON are the dominant N solutes in catchment waters. In the absence of anthropogenic inputs, nitrogen in soils is dominantly derived from plants that fix atmospheric nitrogen ($\delta^{15}N = 0$ ‰). The fractionation associated with fixation results in most soils having $\delta^{15}N$ values of + 2 to + 5 ‰, with cultivated soils having slightly lower average $\delta^{15}N$ values (+ 0.65 ‰) than uncultivated soils (+ 2.73 ‰) (Broadbent et al., 1980). Animal and human wastes typically have values of + 10 to + 20 ‰ (Gormly and Spalding, 1979) and can often be distinguished from other sources due to their distinctive composition. Values for artificial (inorganic) fertilizers, manufactured using atmospheric nitrogen, usually fall between – 2 and + 4 ‰ (Freyer and Aly, 1974), and are often indistinguishable from natural soil nitrogen. Common artificial fertilizers include urea, ammonium nitrate, and potassium nitrate. Mean $\delta^{15}N$ values are + 0.18 ‰ for urea, - 0.91 ‰ for ammonium nitrate, and + 2.75 ‰ for potassium nitrate (Hubner, 1986). Anhydrous ammonia, also commonly used, would be likely to have a $\delta^{15}N$ composition between 0 and 1 ‰, owing to its direct manufacture from atmospheric nitrogen. Organic fertilizers, including plant compost and liquid and solid animal waste, have higher $\delta^{15}N$ values and show a wider range of values, from + 2 to + 30 ‰. $\delta^{15}N$ values for fertilizers and animal/human wastes may be higher than predicted if ammonia volatilisation in the soil is extensive. Studies have shown enrichments of up to 6 ‰ in ground waters due to volatilisation of commercial fertilizers (Kreitler, 1979; Flipse and Bonner, 1985).

In post-1930's Lake Winnipeg sediments, $\delta^{15}N$ values are significantly greater than pre-1930's values and can be reasonably explained by three possible scenarios. Increases in $\delta^{15}N$ values to 5.7 ‰ could be due to an increase in the contribution of nitrogen from plankton, resulting from the influx of growth enhancing nutrients, perhaps from increased fertilizer use. A second explanation for the observed increases is the contribution of artificial and/or natural fertilizers to the lake waters. Although the artificial fertilizers applied to soils in the region have $\delta^{15}N$ values (0 to 1 ‰) lower than those in average natural soils, fertilizers in soils are subject to ammonia volatilisation, which can increase the nitrogen isotope composition by up to 6 ‰, resulting in values of up to 7 ‰. Assuming that moderate volatilisation occurs, altered fertilizers would have compositions of up to 7 ‰. Hence, the increase in fertilizer use, documented to have occurred mostly in the past 30 years (Canadian Fertilizer Institute) could be responsible for observed increases in $\delta^{15}N$ values. However, this does not address the issue that $\delta^{15}N$ values began to increase in the 1930's, prior to extensive artificial fertilizer application in the prairies. Many of the artificial fertilizers were developed in the years directly preceding World War I, although commercial production didn't begin until years later. However, organic fertilizers, including plant compost and liquid and solid animal wastes were applied in the early days of agriculture on the Canadian prairies. Organic fertilizers, which typically have higher $\delta^{15}N$ values than artificial ones, could be responsible for the observed increases in $\delta^{15}N$ values in Lake Winnipeg sediments that begin in the 1930's. A third possible scenario is the contribution of high $\delta^{15}N$ sewage, although it seems unlikely that there would be a continuous source of this material to correspond with a continuous increase in $\delta^{15}N$ values since the 1930's. A combination of the first two scenarios seems most likely. The correspondence of % nitrogen with $\delta^{15}N$ values supports the concept that increasing nutrient levels are responsible for $\delta^{15}N$ increases at the top of the core, rather than sediment-water interface fractionations.

These results are consistent with studies showing that nutrient levels in Lake Winnipeg have increased throughout the twentieth century, particularly in the past 30 years. Kling et al. (2002) concluded that increased nutrients and changes in flow and light regimes have caused increases in phytoplankton biomass and changes to species diversity in the past century. Stainton et al. (2002) found that increases in algal productivity are predominantly from nitrogen-fixing blue-green algae. Evidence of enhanced nutrient levels has also been shown as increased phosphorous concentrations (Simpson and Thorleifson, this volume; Mayer et al., this volume) and increased macrofossil abundances (Telka, this volume) in the top 20 cm or so of the 99-900 cores.

Flood indicators

River catchment hydrology has a significant influence on the mobility and distribution of organic matter, both in the dissolved and particulate state. Particulate organic matter (POM) constitutes the size fraction greater than 0.45 μm while organic matter less than 0.45 μm is termed dissolved organic matter (DOM). Increased runoff and soil erosion during river high water stages generally promotes increased additions of allochthonous DOM, and in most cases, POM to rivers (e.g. Esser and Kohlmaier, 1990). The authors attribute these increases to soil leaching and surface erosion. Assuming that inputs of organic carbon to the lake are significant and that much of this material is incorporated into the lake-bottom sediments, flood events could potentially be recognizable in bottom sediments as increases in organic carbon content.

In a study of riverine DIC, Kendall et al. (2001) have shown that phytoplankton blooms, occurring in response to higher DIC concentrations during flood episodes, could be recognized by enhanced sediment $\%C_{org}$ values and depleted $\delta^{13}C_{org}$ values. During flooding, riverine DIC increases, causing phytoplankton blooms that have a fractionating effect on the carbon isotopes causing depleted $\delta^{13}C_{org}$ values. When DIC is abundant relative to demand, phytoplankton assimilation is not a rate-determining step in carbon consumption and therefore maximum DIC-plankton fractionation occurs, resulting in lower $\delta^{13}C_{org}$ values (Kendall et al., 2001). Conversely, during normal river discharge years, DIC may become limited, resulting in minimum DIC-phytoplankton fractionation and relatively higher $\delta^{13}C_{org}$ values.

It was thought that carbon and nitrogen elemental and isotopic analyses may preserve a record of the rapid influx and deposition of terrestrial plant debris that might be expected to accompany floods. For a unique signature representing flooding events to occur in the lacustrine sedimentary record, the following conditions must apply: (1) non-flood sediments and flood sediments must have sufficiently distinct compositions for the parameters studied, and there must be some detectable biochemical control on the composition of flood sediment organics that distinguishes them from non-flood sediments, and (2) there must be a sufficient volume of material transported and preserved offshore during floods to leave a traceable signature when mixed (i.e. diluted) with lacustrine material.

The association of depletions in $\delta^{13}C_{org}$ values and increases in % C content of riverine DIC with floods (Kendall et al., 2001) provides a useful tool in interpreting the lacustrine sediments of a lake that receives a large influx of water from a major river. Anomalously high % C content coincident with anomalously depleted $\delta^{13}C_{org}$ values in the bottom sediments of Lake Winnipeg (Figure 3) could be interpreted as nutrient influxes associated with flood events. However, cross plots of $\delta^{13}C_{org}$ vs. silt, C_{org} vs. silt, and C_{org} vs. $\delta^{13}C_{org}$ do not reveal any correlations (Figure 5). Shifting one parameter by up to 10 cm in both directions did not improve any of the correlations, thus implying that a lag is not responsible for the lack of correlation. Additionally, other processes contributing to nutrient influx cannot be ruled out for the formation of these layers. Although some of the layers correspond roughly to some of the known floods of the past 200 years, further research on another core is required to corroborate the findings.

C/N_{org} ratios are potentially very useful for identifying floods in lake-bottom sediments, as there is an obvious distinction between C/N_{org} ratios for lacustrine organic matter and terrestrial organic matter. Floods could be indicated by higher C/N_{org} values, which correspond with an influx of terrestrially derived material (with characteristically higher C/N_{org} values). Provided that terrestrial (C_3-type) plants in the watershed have a slightly more depleted character than phytoplankton, depleted $\delta^{13}C_{org}$ compositions in the lake-bottom sediments could indicate floods. During flooding, a larger proportion of terrestrial material would enter the river, transporting this higher percentage to the lake.

C/N_{org} values of Lake Winnipeg sediments are within the range of values typical for lacustrine algae, indicating that a sufficient amount of terrestrial material to offset dilution, has not reached the offshore sediments. However, numerous peaks in C/N_{org} ratios observed down-core could potentially represent increases in the proportion of terrestrial material (Figure 2). Increases in C/N_{org} ratios do not correlate with increases in silt content, which are though to indicate floods, or with ages of known floods. However, variations in the $\delta^{13}C$ value of the DIC between flood and normal river discharge years may provide an explanation for the lack of correlation between anomalously high C/N_{org} ratios and historical Red River floods. This possibility arises due to an increased input of organic material into the south basin during Red River flood episodes.

Grass fire era

Additionally, an increased incidence of grass fires occurred in southern Manitoba between the late 18th and late 19th centuries, caused by fur trade provisioning requirements, agricultural activities and careless visitors to the region (Rannie, 2001). In general, fires volatilize nitrogen in proportion to the heat generated and the amount of organic matter consumed. Pryodenitrification (volitalization of N_2 due to heat) results in significant loss of fixed nitrogen from vegetation and soils. Even though the total N in the soils is reduced after a fire, the available ammonium (NH^{+4}) and nitrate (NO^{-3}) is usually greater after a fire (Kovacic et al., 1986; Covington and Sackett, 1992). With the temporary loss of plant cover and soil micro-organisms, the increase in the availability of NH^{+4} and NO^{-3} can result in a situation known as nitrogen saturation. Hence, runoff during these times would be more rich in nitrogen compounds, especially if the reduction in plant cover has increased soil erosion rates. Nitrogen contents and $\delta^{15}N$ values do increase in the Lake Winnipeg core during the late 18th to late 19th century. This grass fire era, which predates maximum increases in nitrogen fertilization, is potentially responsible for increases the earliest increases in nitrogen contents and $\delta^{15}N$ values in the core.

CONCLUSIONS

- Organic carbon and nitrogen contents of the offshore sediments are low, together comprising less than 2 % of the total sediment.
- Results for C/N_{org} and $\delta^{13}C_{org}$ suggest that lacustrine OM in Lake Winnipeg is derived dominantly from lacustrine algae. Diagenetic alteration of the OM, generally extensive in oxic lakes, does not appear to have significantly altered the compositions of C/N_{org} and $\delta^{13}C_{org}$.
- The constancy of the carbon and nitrogen record over the past 1100 years, excluding the twentieth century, indicates that environmental conditions, such as climate, watershed dynamics and transport mechanisms, have not changed sufficiently during this time to affect these values.
- Isotopic enrichment of $\delta^{13}C_{org}$ values in the top 15 cm of the core suggests increased productivity of aquatic algae, as a result of increased nutrient influx. Results suggest that productivity and hence, eutrophication, began to increase significantly in the 1950's, reaching peak levels only within the past 5 years.
- Increases in nitrogen content and the isotopic enrichment of $\delta^{15}N$ are evident in the top 20 to 30 cm of the core and are likely due to the extensive use of nitrogen fertilizers in the prairies during the latter half of the 20th century.
- Anomalously depleted $\delta^{13}C_{org}$ and enhanced % C_{org} values could provide a record of Red River flooding over the past millennium, although analysis of a second core is recommended for further investigation.

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Table 1. % C_{org}, % N, C/N_{org}, $\delta^{15}N$ and $\delta^{13}C_{org}$ compositions of sediments in Lake Winnipeg 99-900 core 8

Depth cm	C_{org} (%)	N_{org} (%)	C/N_{org}	$\delta^{15}N_{org}$ (‰)	$\delta^{13}C_{orgORIG}$ (‰)	$\delta^{13}C_{orgNORM}$ (‰)
0-1	2.03	0.17	4.9	5.7	-29.4	-27.8
1-2	1.94	0.23	3.9	7.0	-27.4	-25.9
2-3	1.57	0.21	2.7	6.3	-27.1	-25.6
3-4	1.34	0.18	4.3	6.1	-27.2	-25.8
4-5	1.54	0.20	3.1	7.2	-27.1	-25.7
5-6	1.51	0.19	4.1	5.0	-27.2	-25.9
6-7	1.85	0.24	3.2	6.6	-27.1	-25.9
7-8	1.69	0.17	6.6	5.2	-27.2	-26.1
8-9	1.66	0.22	4.4	5.5	-27.1	-26.1
9-10	1.69	0.21	4.1	5.2	-27.0	-26.0
10-11	1.80	0.22	2.9	6.7	-26.9	-26.0
11-12	1.83	0.22	3.3	5.2	-26.9	-26.1
12-13	1.75	0.20	3.8	6.0	-27.0	-26.3
13-14	1.70	0.21	3.2	5.7	-27.1	-26.4
14-15	1.67	0.21	3.9	4.5	-27.1	-26.5
15-16	1.67	0.19	5.2	4.6	-27.3	-26.8
16-17	1.85	0.20	5.0	6.3	-27.1	-26.7
17-18	1.68	0.18	3.7	5.6	-26.5	-26.1
18-19	1.46	0.18	2.9	5.2	-26.6	-26.3
19-20	1.22	0.17	4.2	4.6	-26.7	-26.4
20-21	1.44	0.18	3.4	4.4	-26.5	-26.3
21-22	1.51	0.18	3.4	4.8	-26.6	-26.4
22-23	1.36	0.16	5.6	3.1	-26.7	-26.5
23-24	1.38	0.17	4.5	3.1	-26.6	-26.5
24-25	1.37	0.16	3.5	3.9	-26.5	-26.4
25-26	1.36	0.17	2.9	3.7	-26.5	-26.4
26-27	1.28	0.14	5.4	4.2	-26.5	-26.4
27-28	1.28	0.14	4.6	4.6	-26.5	-26.4
28-29	1.28	0.16	3.1	4.6	-26.6	-26.5
29-30	1.25	0.15	4.1	3.7	-26.7	-26.7
30-31	1.02	0.15	4.3	4.5	-26.5	-26.5
31-32	1.38	0.14	4.0	4.0	-26.6	-26.6
32-33	1.38	0.14	4.0	3.2	-26.4	-26.4
33-34	0.96	0.13	4.0	2.4	-26.7	-26.7
34-35	1.12	0.13	3.7	2.7	-26.5	-26.5
35-36	1.21	0.15	4.8	3.6	-26.7	-26.7
36-37	1.27	0.14	3.2	3.6	-26.5	-26.5
37-38	1.18	0.14	5.4	2.9	-26.5	-26.5
38-39	1.19	0.14	4.1	3.8	-26.4	-26.4
39-40	1.04	0.14	3.8	3.6	-26.5	-26.5
40-41	1.23	0.14	3.1	3.8	-26.3	-26.3
41-42	1.44	0.16	3.4	4.0	-26.2	-26.2
42-43	1.27	0.14	5.1	2.7	-26.5	-26.5
43-44	1.29	0.15	4.7	2.2	-26.3	-26.3
44-45	1.13	0.14	4.1	3.0	-26.5	-26.5
45-46	1.14	0.14	4.8	4.1	-26.5	-26.5
46-47	1.28	0.13	6.3	3.6	-26.5	-26.5

Table 1 continued

Depth cm	C_{org} (%)	N_{org} (%)	C/N_{org}	$\delta^{15}N_{org}$ (‰)	$\delta^{13}C_{orgORIG}$ (‰)	$\delta^{13}C_{orgNORM}$ (‰)
47-48	1.25	0.14	4.4	4.0	-26.3	-26.3
48-49	0.96	0.13	5.1	1.7	-26.6	-26.6
49-50	1.09	0.14	4.1	3.0	-26.3	-26.3
50-51	1.08	0.12	4.2	3.2	-26.1	-26.1
51-52	1.13	0.14	3.9	4.4	-26.2	-26.2
52-53	1.20	0.14	3.5	3.7	-26.3	-26.3
53-54	1.17	0.12	4.6		-26.3	-26.3
54-55	1.23	0.16	3.7	3.1	-26.4	-26.4
55-56	1.07	0.15	3.3	3.2	-26.4	-26.4
56-57	1.18	0.16	3.7	3.7	-26.2	-26.2
57-58	0.95	0.14	3.7	2.5	-26.0	-26.0
58-59	1.16	0.13	4.4	2.3	-26.2	-26.2
59-60	1.10	0.13	4.0	3.6	-26.2	-26.2
60-61	1.07	0.14	2.9	3.7	-26.3	-26.3
61-62	1.08	0.13	4.9	3.6	-26.4	-26.4
62-63	1.25	0.14	5.1	4.4	-26.4	-26.4
63-64	1.39	0.13	4.0	2.3	-26.2	-26.2
64-65	1.17	0.13	5.5	4.5	-26.3	-26.3
65-66	1.07	0.13	4.3	3.1	-26.1	-26.1
66-67	1.09	0.14	3.7	3.8	-26.1	-26.1
67-68	1.06	0.14	4.7	3.6	-26.3	-26.3
68-69	1.19	0.15	2.9	4.1	-26.3	-26.3
69-70	1.16	0.11	5.6		-26.3	-26.3
70-71	1.12	0.12	3.8	4.6	-26.3	-26.3
71-72	1.18	0.15	5.0	4.0	-26.5	-26.5
72-73	1.21	0.14	5.5	1.6	-26.3	-26.3
73-74	1.24	0.15	4.6	4.2	-26.3	-26.3
74-75	1.22	0.14	5.8	4.4	-26.3	-26.3
75-76	1.24	0.15	4.1	3.4	-26.1	-26.1
76-77	1.04	0.12	3.7	3.3	-26.1	-26.1
77-78	1.08	0.12	4.0	3.1	-26.2	-26.2
78-79	1.40	0.15	5.4	4.2	-26.5	-26.5
79-80	1.32	0.14	5.1	3.6	-26.2	-26.2
80-81	1.21	0.12	5.2	2.9	-26.4	-26.4
81-82	0.83	0.13	3.8	3.1	-26.3	-26.3
82-83	1.04	0.12	3.8	4.3	-25.8	-25.8
83-84	1.10	0.14	5.5	3.3	-26.2	-26.2
84-85	1.04	0.13	3.8	2.0	-26.1	-26.1
85-86	1.15	0.12	5.6	2.8	-26.3	-26.3
86-87	1.18	0.12	4.7		-26.2	-26.2
87-88	1.14	0.13	4.6	4.2	-26.2	-26.2
88-89	1.20	0.14	4.9	3.5	-26.4	-26.4
89-90	1.16	0.13	3.8	3.6	-26.3	-26.3
90-91	1.05	0.11	3.6		-26.1	-26.1
91-92	1.18	0.13	5.8	3.3	-26.2	-26.2
92-93	1.08	0.13	5.1	3.4	-26.3	-26.3
93-94	1.05	0.13	4.8	4.8	-26.2	-26.2

Table 1 continued

Depth cm	C_{org} (%)	N_{org} (%)	C/N_{org}	$\delta^{15}N_{org}$ (‰)	$\delta^{13}C_{orgORIG}$ (‰)	$\delta^{13}C_{orgNORM}$ (‰)
94-95		0.13		4.7		
95-96	1.18	0.14	4.0	3.0	-26.2	-26.2
96-97	1.30	0.13	6.5	2.6	-26.3	-26.3
97-98	1.09	0.13	3.5	3.5	-25.9	-25.9
98-99	1.04	0.13	5.0	3.3	-25.9	-25.9
99-100	1.11	0.13	3.7	4.4	-25.9	-25.9
100-101	1.10	0.10	5.8		-25.9	-25.9
101-102	1.16	0.13	6.2	2.6	-26.1	-26.1
102-103	1.15	0.12	4.5	4.0	-26.0	-26.0
103-104	1.03	0.14	3.8	3.5	-26.1	-26.1
104-105	1.24	0.15	5.1	3.7	-26.4	-26.4
105-106	1.17	0.13	4.1	3.1	-26.1	-26.1
106-107	1.23	0.13	4.9	3.2	-26.1	-26.1
107-108	1.20	0.11	4.8		-26.1	-26.1
108-109	1.11	0.12	3.5	3.2	-26.2	-26.2
109-110	1.12	0.14	4.7	3.2	-26.3	-26.3
110-111	0.66	0.13	2.3	4.8	-26.4	-26.4
111-112	0.99	0.12	3.7		-26.3	-26.3
112-113	1.66	0.13	7.1	3.9	-26.2	-26.2
113-114	1.18	0.14	3.5	3.8	-26.0	-26.0
114-115	1.01	0.12	3.7	3.4	-26.0	-26.0
115-116	0.80	0.11	3.3		-25.9	-25.9
116-117	1.15	0.10	5.6		-26.1	-26.1
117-118	1.12	0.12	3.7	3.2	-26.2	-26.2
118-119	1.10	0.12	5.5	3.4	-26.3	-26.3
119-120	0.93	0.14	3.8	3.0	-26.4	-26.4
120-121	1.08	0.13	3.7	2.9	-26.3	-26.3
121-122	1.24	0.14	4.1	2.1	-26.2	-26.2
122-123	1.01	0.14	4.4	3.9	-26.3	-26.3
123-124	1.20	0.13	4.5	4.1	-26.2	-26.2
124-125	1.06	0.11	4.5		-26.4	-26.4
125-126	1.12	0.12	3.4	5.0	-26.3	-26.3
126-127	1.36	0.13	6.8	2.3	-26.4	-26.4
127-128	1.05	0.13	4.1	2.7	-26.8	-26.8
128-129	1.29	0.13	4.2	3.0	-26.1	-26.1
129-130	1.01	0.13	4.8	3.6	-26.2	-26.2
130-131	1.08	0.13	4.6	4.3	-26.2	-26.2
131-132	1.06	0.13			-26.2	-26.2
132-133	1.19	0.14	4.5	2.8	-26.2	-26.2
133-134	0.98	0.10	5.6		-26.2	-26.2
134-135	1.20	0.12	3.9	2.6	-25.9	-25.9
135-136	1.10	0.13	3.8	3.1	-26.0	-26.0
136-137	1.15	0.13	5.0	4.2	-25.9	-25.9
137-138	1.14	0.13	3.7	4.0	-25.7	-25.7
138-139	1.04	0.11	3.2		-25.7	-25.7
139-140	1.01	0.11	3.3		-25.8	-25.8
140-141	1.09	0.12	3.5		-26.2	-26.2

Table 1 continued

Depth cm	**C_{org}** (%)	**N_{org}** (%)	**C/N_{org}**	**$\delta^{15}N_{org}$** (‰)	**$\delta^{13}C_{orgORIG}$** (‰)	**$\delta^{13}C_{orgNORM}$** (‰)
141-142	1.05	0.13	4.3	3.5	-26.3	-26.3
142-143						
143-144	1.20	0.13	5.5	2.7	-26.3	-26.3
144-145	1.06	0.10	3.9		-26.1	-26.1
145-146	0.99	0.12	4.1		-25.9	-25.9
146-147	1.02	0.11	4.4		-26.0	-26.0
147-148	0.99	0.11	4.7		-26.1	-26.1
148-149	1.01	0.11	4.5		-26.0	-26.0
149-150	1.01	0.11	4.9		-26.3	-26.3
150-151	1.21	0.12	4.4	3.9	-26.0	-26.0
151-152	1.22	0.14	5.5	3.1	-26.3	-26.3
152-153	1.18	0.14	4.8	2.7	-26.3	-26.3
153-154	1.20	0.14	5.4	1.8	-26.1	-26.1
154-155	1.14	0.12	5.4	3.2	-26.1	-26.1
155-156	1.20	0.13	5.5	3.5	-26.1	-26.1
156-157	1.55	0.18	4.0	5.5	-27.1	-27.1
157-158	1.10	0.13	3.1	2.6	-26.1	-26.1
Mean	**1.22**	**0.14**	**4.3**	**3.8**	**-26.4**	**-26.2**
Std. Dev.	**0.23**	**0.03**	**0.89**	**1.09**	**0.41**	**0.26**

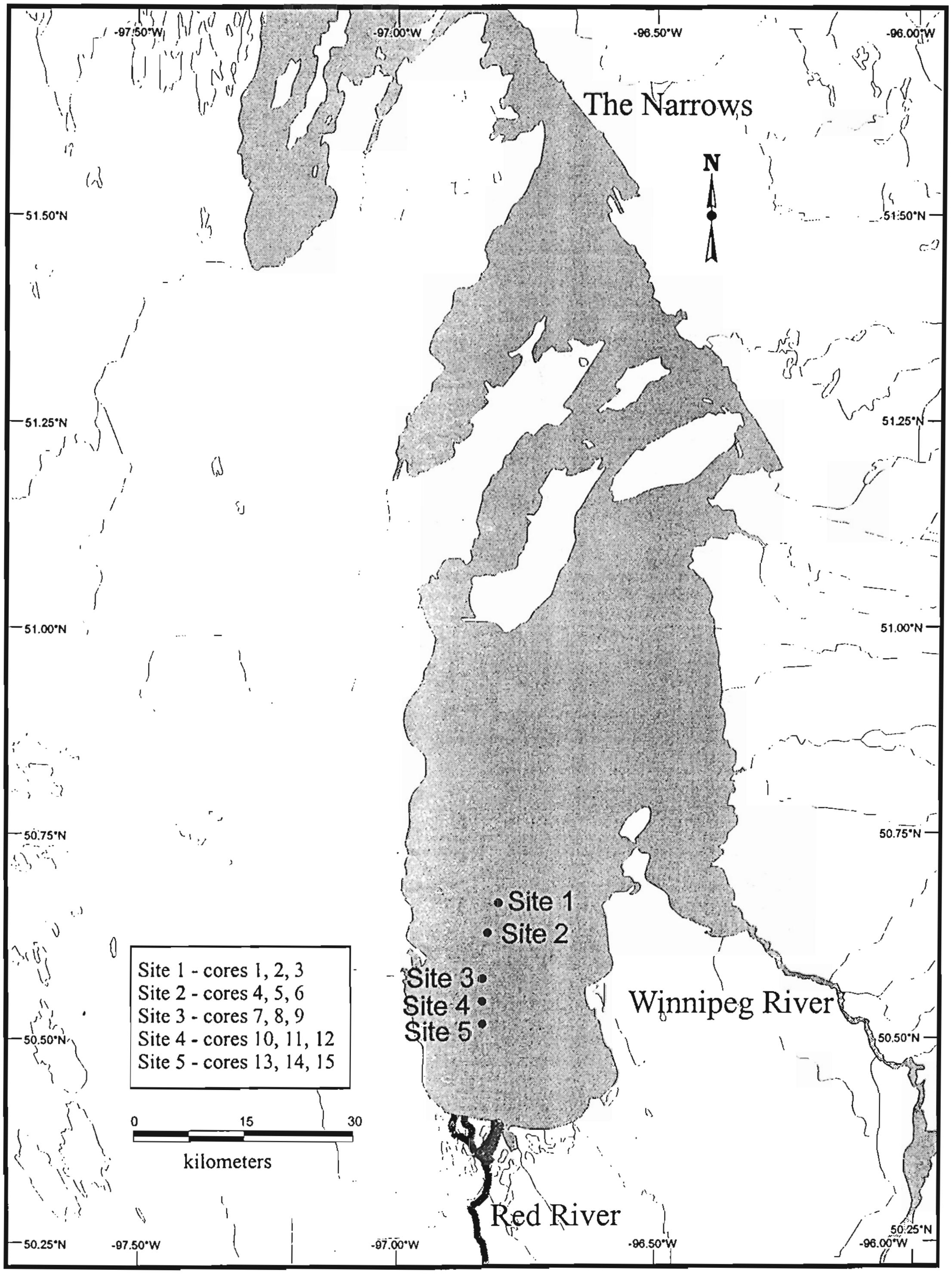

Figure 1. Map of southern Lake Winnipeg showing locations of coring sites

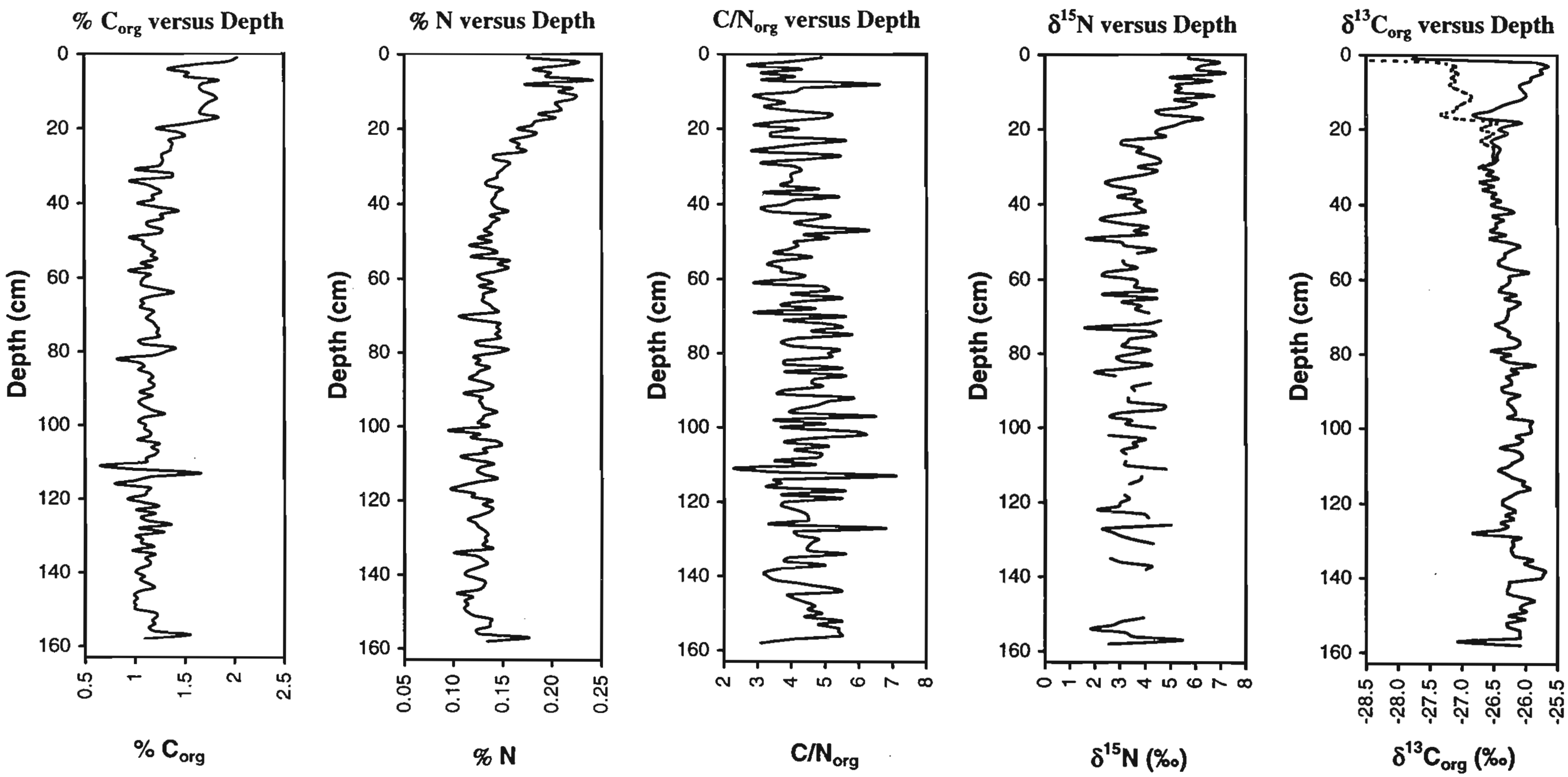

Figure 2. Down-core variations in % C_{org}, % N, C/N_{org}, $\delta^{15}N$ and $\delta^{13}C_{org}$ values of sediments in Lake Winnipeg 99-900 core 8. For $\delta^{13}C_{org}$, original values are shown with a dashed line, while values normalized to counteract the 'Suess Effect' (the historic depletion of $\delta^{13}C$ in atmospheric CO_2 caused by the burning of fossil fuels) are shown with a solid line (Keeling et al., 1989).

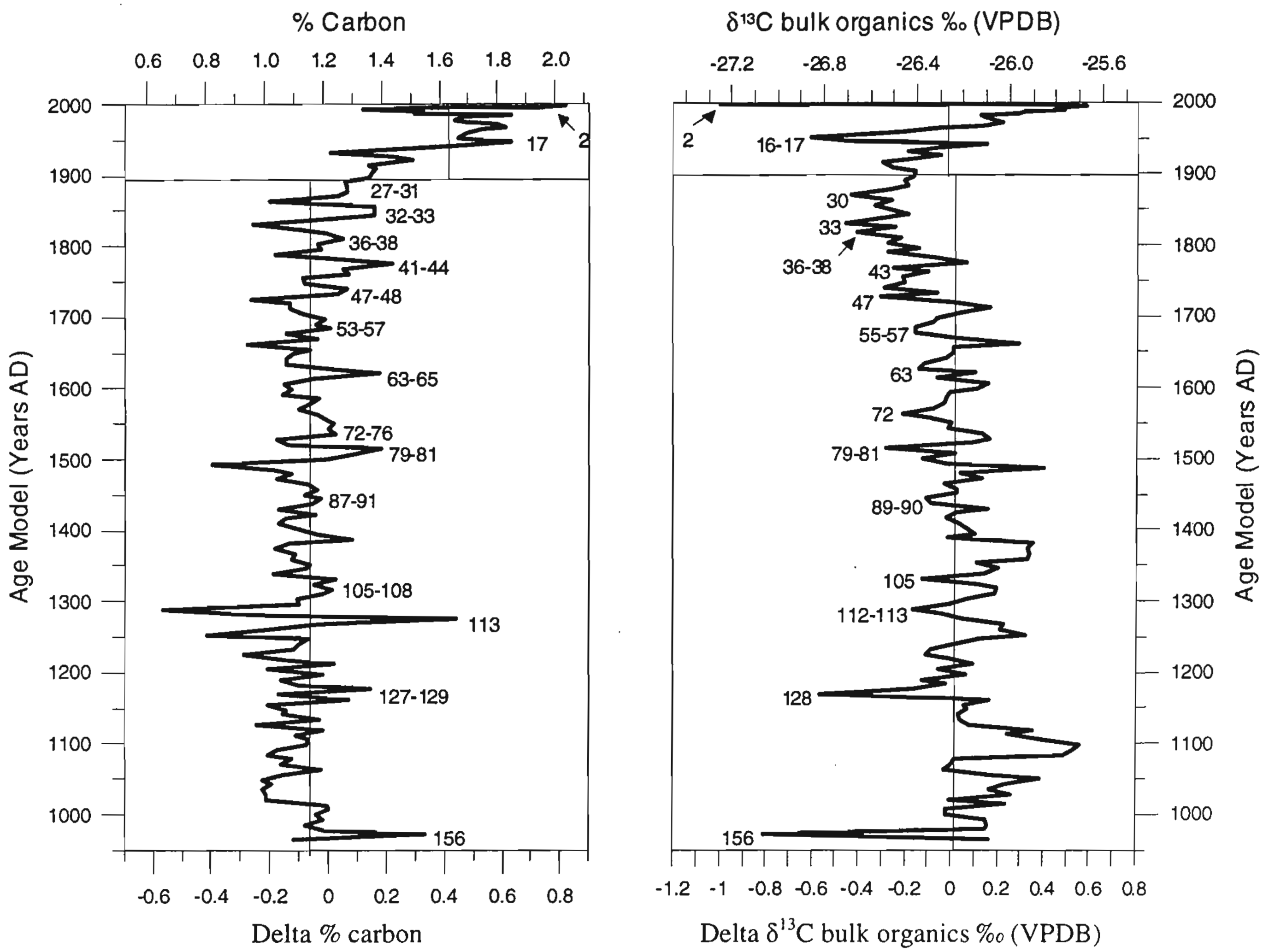

Figure 3. Down-core departure from average % C_{org} and $\delta^{13}C_{org}$ values of sediments in Lake Winnipeg 99 -900 core 8. Averages are different for pre- and post-1900 sediments to account for anthropogenic inputs of organics. Depths (in cm) of anomalously depleted $\delta^{13}C_{org}$ and enhanced $\%C_{org}$ are indicated in the figure.

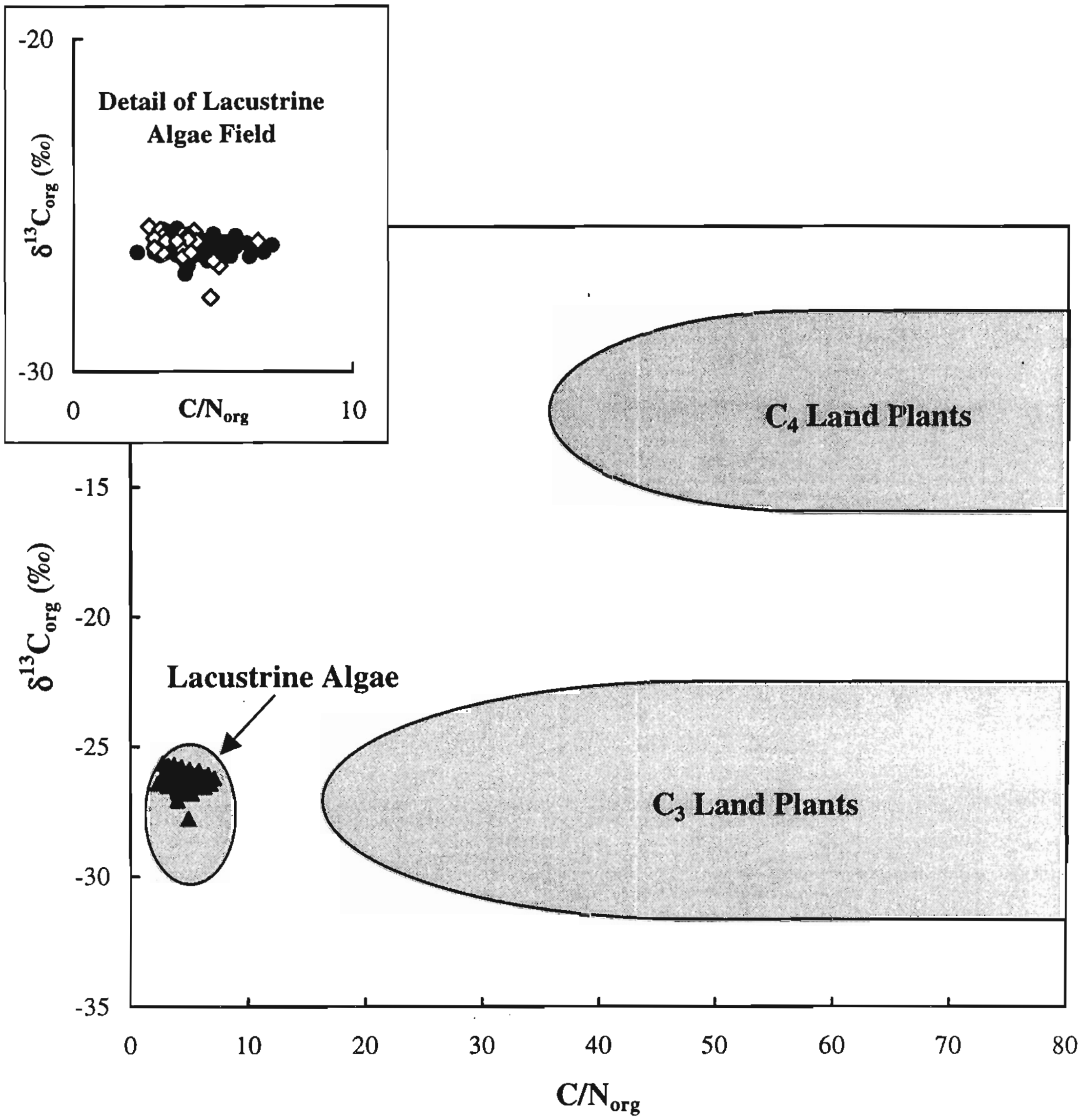

Figure 4. Plot of C/N_{org} versus $\delta^{13}C_{org}$, showing fields of unique $\delta^{13}C_{org}$-C/N_{org} compositions for lacustrine algae, C_3 land plants and C_4 land plants (after Meyers, 1994 and Meyers and Lallier Vergès, 1999). Marine algae field is not illustrated. Results for Lake Winnipeg 99-900 core 8 samples (black triangles; n=155) and fall within the lacustine algae field, indicating that organic matter in these sediments is dominated by material derived from lacustrine algae. The detail shows that samples in the upper 20 cm of the core (diamonds) have, on average, lower C/N_{org} values than samples below this depth (circles). $\delta^{13}C$ values have been normalized to counteract the 'Suess Effect'.

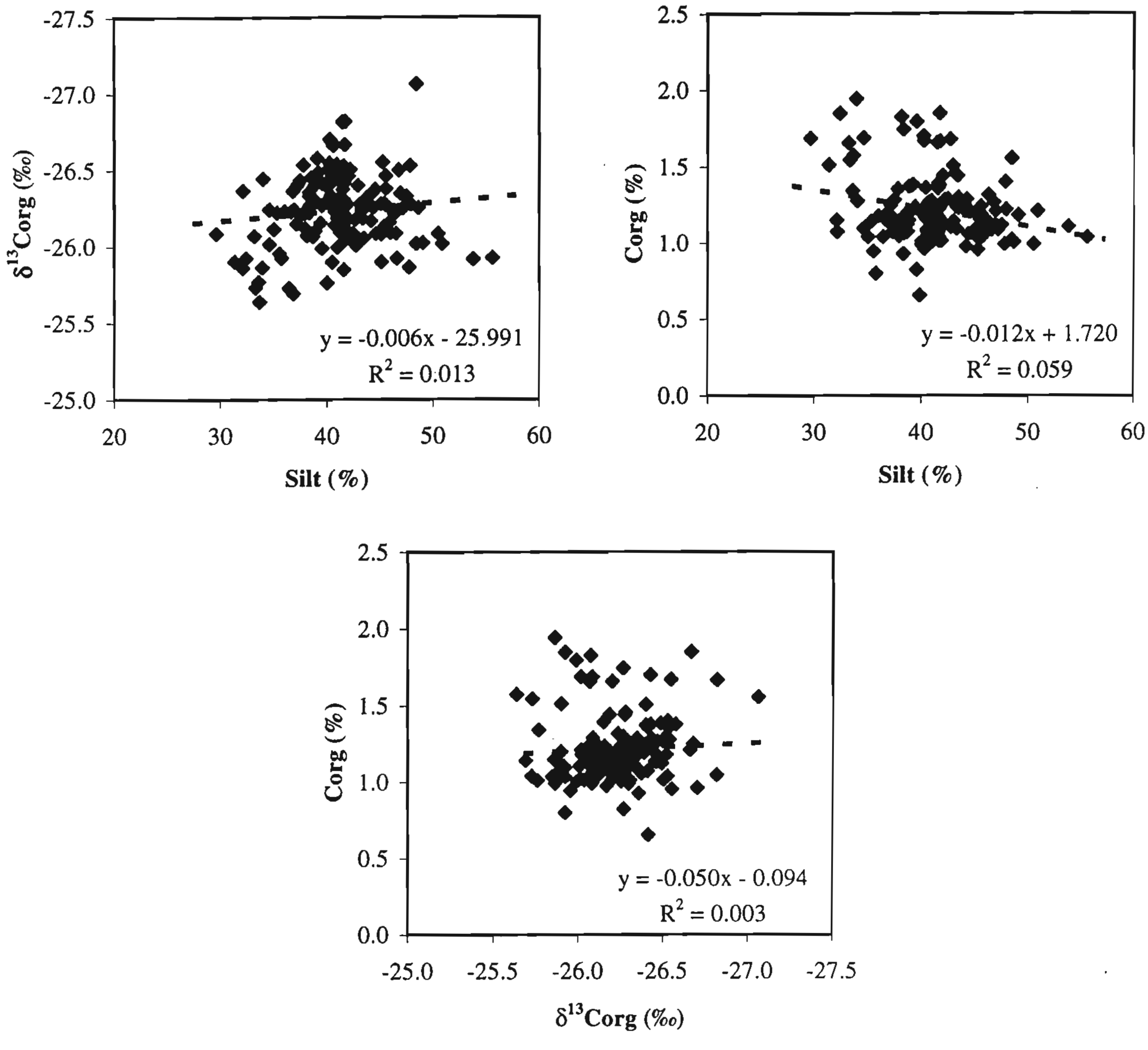

Figure 5. Cross plots of $\delta^{13}C_{org}$ vs. silt, C_{org} vs. silt, and C_{org} vs. $\delta^{13}C_{org}$ for Lake Winnipeg 99-900 core 8

6. Paleontological analyses of the cores

6.1 Macrofossil analysis of Lake Winnipeg 99-900 cores 7 and 9

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ABSTRACT

Following the 1997 Red River flood, research addressing the history and controls on the flood hazard included analysis of sediments in Lake Winnipeg to assess flood history and drainage basin evolution. To do so, 15 cores, each about 1.5 m long, were collected from the south basin during a cruise of the Canadian Coast Guard Ship (CCGS) Namao in August 1999, designated Geological Survey of Canada (GSC) cruise 99-900. Macrofossils recovered from three cores for radiocarbon dating were also examined to support paleoenvironmental analysis. The cored sediments are attributed approximately to the past 1100 years on the basis of radiochemistry, paleomagnetic analysis, palynology and radiocarbon dating. The macrofossil record is dominated by aquatic fauna, suggesting that deep-water conditions have persisted for the past 1100 years. A comparison to macrofossil abundance in nearshore deposits indicates that the transport of coarse terrestrial organic material to these deeper waters is rare. Evidence of floods, in the form of correlatable layers rich in terrestrially-derived material, was not observed. Four-fold increases in macrofossil abundance, and in the insect group Chironomidae, in the top 20-30 cm of the cores implies that nutrient influx began to increase during the period AD 1874 to AD 1934. There is no indication in the form of pre-20th century diminishing numbers or partially-decomposed fossils that the down-core decrease is due to post-burial decomposition. The occurrence of intervals rich in charred remains may indicate the occurrence of fires in AD 1912-1929, AD 1429-1461 and AD 1024-1056.

INTRODUCTION

The Red River flood of 1997 was a major disaster that drove 103,000 people from their homes. Much is being done, however, to reduce comparable damage and disruption in the future through enhanced dikes and diversions, as well as revised land use and water management practices. The design of these works requires an optimal understanding of the risk. Research therefore has addressed the nature of the largest known flood, in 1826, whether comparable large floods have occurred in recent centuries, and how geomorphic, climatic, land use, and tectonic factors may be changing the flood hazard. These issues are being addressed by examining the geomorphic processes governing evolution of the Red River, archival records of flood history, floodplain stratigraphic records, tree-ring records, changes in valley gradients, and by examining the stratigraphy of Lake Winnipeg sediments (Thorleifson et al., 1998). The coring in Lake Winnipeg, receiving basin of waters from the Red River, was designed to sample sites most likely to have recorded any influx of sediments from the Red River that may have occurred. In addition to recording gradual changes in Red River sediment transport, it was thought that flood events might be recognizable, due to unique properties allowing differentiation from other sediments in the lake, although it was unclear what attribute would best distinguish flood-related sediments. The cores therefore were thoroughly analyzed for chronology, as well as for a broad range of physical, chemical and biological properties to determine which, if any, would record a history of flooding.

In order to obtain floral and faunal macrofossil profiles, used to provide information that might indicate changes in the lake environment, cores 5, 7 and 9 were analyzed for macrofossil content. In lakes, plant macrofossil analysis is most commonly used for reconstruction of former lake-level changes related to climate, occurring over time periods on the order of thousands of years (e.g. Hannon and Gaillard, 1997). Previous work examining the macrofossils of Lake Winnipeg sediments indicate that lake-level change during the past 1100 years has not affected macrofossil trends in the upper 1.5 m of sediments (Telka, 2000). Given the time scale of the present study, the objective was not to provide information on lake-level changes, but rather, to look for evidence of flooding or of basin evolution, including anthropogenic impacts. It was thought that the macrofossil record might preserve a record of the rapid influx and deposition of terrestrial macrofossils that might be expected to accompany floods, thus providing a record of flooding in the region. The macrofossil record was also examined for trends in the upper portion of the core that could be related to anthropogenic impacts, in particular the eutrophication of lake waters. The occurrence of charred remains was also documented for one of the cores, and it may provide a record of fires in the watershed. Samples of well-preserved insect and wood remains were also obtained for radiocarbon dating, for the purpose of developing a chronological model for sedimentation (See Telka, this volume).

* Italicized text is repeated in each chapter

LAKE WINNIPEG

Lake Winnipeg, located in central North America, is the eleventh largest lake in the world, having an area of 24,000 km² (Hutchinson, 1975). The lake straddles the contact between Paleozoic carbonate rocks to the west and Precambrian igneous and metamorphic rocks of the Canadian Shield to the east. A smaller south basin, approximately 90 km by 40 km, is separated from a north basin, approximately 240 km by 100 km, by a narrow passage known as The Narrows. The glacially-scoured depression in the rocks underlying the lake, with a depth of 50-100 m, is largely filled with fine-grained glacial Lake Agassiz sediments, overlain by up to 15 m of post-glacial Lake Winnipeg sediments (Todd and Lewis, 1996). The bathymetry of the lake is shallow and the bottom is flat, with depths averaging 9 m in the south basin and 16 m in the north basin. The lake has a catchment area extending from the Rocky Mountains to very near Lake Superior, including the basins of the Winnipeg, Saskatchewan, Red, Dauphin and numerous smaller rivers. Outflow from the lake is north to Hudson Bay, through the Nelson River. Post-glacial uplift has caused the north end of the basin to rise relative to the south, causing a gradual rise of lake levels that continues at present (Lewis et al., 2000). The mean annual temperature of the region, recorded at Gimli, is +1.4°C, although the continental climate of the region ranges from hot summers to very cold winters. The mean annual precipitation is 50.8 cm. The lake is ice free from early May to late November (Ice Thickness Climatology, 1992) and ice cover from November to May is consistently thick and continuous. The lake waters are poorly stratified to unstratified and during the summer months water temperatures range from +17°C in the north basin to +19.5°C in the south basin (Todd, 1996), hence bottom sediment temperatures are equally warm in mid-summer. The lake supports a commercial fishery, it is a major destination for recreation, and lake levels are regulated to optimize hydroelectric power generation on the Nelson River.

SAMPLING AND ANALYTICAL METHODS

Selection of five sampling sites in the south basin of Lake Winnipeg was based on proximity to the Red River mouth and on the absence of ice scour on sidescan sonar records previously obtained in 1994 on the 94-900 Namao cruise (Lewis et al., this volume) (Figure 1). Site 5 was the southernmost point on the north-south survey line that lacked ice scour. Sampling was conducted in calm weather on August 24, 1999 from the CCGS Namao. Three cores were obtained at each of the five sites using a gravity corer consisting of a 100 kg weightstand over a 2 m steel pipe with a 10 cm diameter plastic liner tube. The length of the cores ranged from 107 cm to 170 cm. The cores were sealed, labelled and transported to Gimli, Manitoba on August 29, where they were refrigerated, and subsequently transported via refrigerated truck to the GSC Atlantic core storage facility in Dartmouth, N.S. A monitoring device attached to the core bundle indicated that the sediments did not exceed a temperature of 19°C at any time during transport. Paleomagnetic and physical property data, determined at the laboratory of Professor J.W. King at the University of Rhode Island, provided information used to select cores that would be representative of the offshore sediments (King et al., this volume). Paleomagnetic profiles indicated more rapid accumulation of sediments at the more northerly sites and hence a higher resolution for examining environmental change. Based on these observations, core 8 (site 3), and core 4 (site 2) and core 3 (site 1) were selected as the primary records for detailed study.

Because a large amount of material is required to obtain an adequate number of sparsely-occurring macrofossils, nearby cores were selected for this purpose. Initially, cores 5 and 7 were selected for macrofossil analysis. However, insufficient material was sampled from core 5 and subsequently a section of the core was found to be missing, thus prohibiting re-sampling. Core 9 was then analyzed to corroborate the macrofossil stratigraphy for core 7. Cores 7 and 9 were selected on the basis of proximity to the primary core, good paleomagnetic profiles indicating an intact stratigraphy and good correlation of paleomagnetic records for cores 7 and 9 with that of the well-dated core 8.

The working half of cores 7 and 9 were subsampled at GSC facilities in Dartmouth in 5-cm slices. A total of 29 and 28 samples were obtained from cores 7 and 9, respectively. Between 1 and 5 cm of material from the top of core 7 was inadvertently mixed with deeper sediments due to a core labelling error. Analysis of this interval therefore was disregarded. Each sample, ranging from 100 to 200 mL (wet) in volume, was placed in a sealed plastic bag.

Macrofossil preparation and identification were performed by the author. Initially the samples were weighed and the volumes approximated using a water displacement technique. Using warm tap water, the remaining sediment was gently sieved through nested 40, 60 and 230 mesh Canadian Standard Series sieves (mesh openings of 0.425 mm, 0.25 mm and 0.063 mm respectively). The sieved residue greater than 0.25 mm was examined using a binocular microscope, and plant and animal fossil remains were isolated for identification and potential radiocarbon dating. The retained plant and insect macrofossils were counted, and identified with the aid of the microscope.

RESULTS

Faunal and floral macrofossil abundances for core 7 are presented in Tables 1 and 2, respectively. Faunal and floral macrofossil abundances for core 9 are presented in Tables 3 and 4, respectively. Data tables include the depth (in cm) of the sampling interval below the top of the core and the number of identifications of all taxa (including common names) at each depth. In addition, habitat designations were assigned to many of the taxa and include aquatic taxa (a), aquatic emergent taxa (ae), aquatic to shoreline taxa (a/s), shoreline taxa (s), shoreline to terrestrial taxa (s/t), terrestrial taxa (t), and terrestrial tree taxa (tr). In some cases the designation was difficult to assign. This was especially true for some families of beetles (Coleoptera), specifically the semi-aquatic beetles that inhabit the littoral zone of aquatic environments. For example, ground beetles (Carabidae) and families of the rove beetle (Staphylinidae) may be terrestrial, but some species are hygrophilous, occurring regularly in the vicinity of water. Other families of beetles include species that are ecological generalists, occupying two or more habitats. Occurrences of charcoal and non-biogenic material, such as plastic and vivianite, are also noted in Tables 2 and 4. Vivianite, an iron phosphate mineral, is a weathering product of Fe-Mn phosphates in pegmatites. The charred remains include numerous unidentifiable charred fragments, as well as a few identifiable charred insect fossil remains. Identifiable charred remains were documented in the tables under specific taxa headings rather than under the charcoal heading.

Down-core variations in total macrofossil abundance for both cores are illustrated in Figure 2. The total count of macrofossils excludes fragments of unidentifiable charred organic remains, but includes identified charred remains. Down-core variations in abundance of the five dominant taxa in both cores are shown in Figure 3. The number of identifications of charred organic remains in core 9 was recorded and is illustrated with respect to depth in Figure 4. Charred remains were also identified in core 7, but were not quantified. Caution should be exercised when interpreting this data, since charcoal easily disintegrates into smaller fragments, resulting in multiple separate identifications. It is not the absolute number of identifications that is significant, but rather the occurrence of layers having a greater relative abundance of charred remains.

Macrofossil abundance and dominant taxa

The macrofossil content of the sediments was low, yielding dominantly insect fossils with smaller numbers of plant remains. Similar macrofossil abundances were noted for cores 7 and 9, with peak abundances near the tops of both cores (Figure 2). Most of the identifications were of arthropod remains, consisting dominantly of exoskeletal fragments. The 5 taxa that dominated the record were common to both cores, and included midge larval head capsules (Chironomidae), water flea egg cases (*Daphnia* sp.) and ostracode valves (Ostracoda), as well as flatworm cocoons (Tubellaria) and immature mayfly mandibles (Ephemeroptera) (Figure 3). Beetle (Coleoptera) fossil remains were also present, with many of the taxa belonging to aquatic or semi-aquatic families. Occasional occurrences of fossil fragments of clam (Pelecypoda) periostracum, fish scales and bone, along with fragments of fossil beetles, mites and other terrestrial arthropods were also noted. Fossils of adult aquatic/semi-aquatic insects included water boatmen (Corixidae), shore bugs (Saldidae), predaceous diving beetles (Dytiscidae), water scavenger beetles (Hydrophillidae) and minute moss beetles (Hydraenidae).

Very few seeds were recovered, the most common being cattail (*Typha* sp.). Rare occurrences of composites (Asteraceae), thistle (*Cirsium* sp.), grasses (Poaceae), willow herb (*Epilobium* sp.), violet (*Viola* sp.), water milfoil (*Hippuris* sp.) and spike rush (*Eleocharis* sp.) comprised the remaining macrofossil seeds recovered. Macrofossil remains of trees included very small needle fragments, some being charred, of spruce (*Picea* sp.), larch (*Larix laricina*) and pine (*Pinus* sp.).

Variations with depth

Macrofossil abundance is relatively constant over much of the length of the cores, with increases only in the top 20 to 30 cm (Figure 2). The number of identifications in core 7 ranges from 85 to 690, with increases beginning around 20 cm, and rising up-core to reach peak values in the uppermost interval (5-10 cm). The number of identifications in core 9 ranges from 140 to 930, with increases beginning at 30 cm, and rising up-core to peak values in the uppermost interval (0-5 cm).

The down-core variations in abundance of the two most abundant macrofossils, Chironomidae and *Daphnia*, closely resembles the pattern observed for overall macrofossil abundance (Figure 3). Ostracoda, Tubellaria and Ephemeroptera exhibit somewhat different down-core trends in abundance, showing greater variation of abundance with depth. Similar and comparable trends are evident for each of the two cores.

Charred organic remains

Three intervals in core 9 (130-135 cm, 80-85 cm and 20-25 cm) contain a greater abundance of charred organic remains. The highest numbers of charred remains recovered are from the base of the core, with counts approaching 750 fragments. Many of the charred fragments are small (~1 mm), while others are smaller, sliver-shaped fragments.

DISCUSSION

The macrofossil record of recent lake sediments

Macrofossils found in lake sediments consist of the remains of aquatic plants and animals living in the lake (authigenic) and the remains of organisms transported from terrestrial sources (allogenic), both from the shoreline and from inland terrestrial locations. Lake environments tend to be dominated by aquatic plants and animals, although terrestrial macrofossils are commonly transported to lakes by flowing water, wind or other mechanisms. The majority of material transported by flowing water is deposited near the shoreline of the lake, with decreasing occurrence towards the center of the lake. Some of this material, for example the buoyant seeds derived from shoreline vegetation, is further transported to deeper water by flotation. Insects of terrestrial origin can be transported to deeper water during flight or by wind.

Aquatic flora are more susceptible to the early diagenetic degradation that prevails in oxic environments, compared with aquatic fauna or terrestrial flora and fauna, resulting in most lacustrine plant material becoming an indistinguishable portion of the 60-70 % of lake-bottom sediments comprised of humic material (Ishiwatari, 1985). As a result of rapid and effective early diagenesis, the resistance of the macrofossil to physical, chemical and biological degradation largely controls its occurrence in the lacustrine sedimentary record. Materials such as shells, fish bones and the skeletal portions of insects and crustaceans, as well as seeds, wood and the waxy cuticular coverings of leaves and needles from vascular plants, are more refractory and tend to have a much greater presence in the record.

The most readily apparent inference that can be made from aquatic plant macrofossil analyses is water depth or shoreline proximity, based on the presence and abundance of short-transport shoreline and marsh-dwelling taxa (Telka, 2000). Most shoreline plants grow in a thin band around the shoreline in which the water depth is 1 meter or less. The basinward or shoreward migration of the band of shoreline vegetation can be interpreted as the shallowing or deepening of lake waters, respectively. The occurrence of sparse, long-transport taxa, however, would not reliably provide information on shoreline proximity.

Previous macrofossil studies of Lake Winnipeg sediments

A detailed macrofossil study of Lake Winnipeg and glacial Lake Agassiz sediments was previously conducted in order to obtain terrestrial plant and animal remains for AMS dating and to obtain paleoenvironmental information, particularly with respect to shoreline proximity (Telka, 2000). The results showed that shoreline-indicator macrofossils were abundant near the base of the Lake Winnipeg sediments (approximately 7.5 m depth) but very sparse near the top. A core from the south basin was divided into 5 zones on the basis of floral macrofossil composition and the abundance of shoreline proximity indicators. The basal zone (739-721 cm), which consisted of Lake Agassiz sediments, had very few macrofossils, suggesting relatively deep-water conditions during deposition. The overlying zone (721-677.5 cm) contained an abundant and diverse assemblage of plant macrofossils, dominated by terrestrial or shoreline taxa (grasses, composites, coast-blite, dock and skunkweed) and saline water taxa (horned pondweed, spike rush and northern seaside buttercup). The evidence indicated that the shoreline was much closer to the present-day offshore location of the cores and that the water was much shallower, with evidence of evaporative conditions. Throughout the third zone (677.5-550 cm), shoreline-indicator macrofossils decreased dramatically, indicating a rise in lake level in the basin. The zone underlying the uppermost zone (550-500 cm) was dominated by cat-tails and bulrushes, indicative of marsh conditions. The upper zone (500-0 cm) was characterized by a decrease in plant macrofossil abundance, suggesting expansion of the south basin and the establishment of deeper-water conditions.

INTERPRETATION

Shoreline proximity and ecosystem dynamics

Throughout the lengths of the two offshore cores examined, the macrofossil record is dominated by freshwater benthos, including aquatic insects and crustaceans, while shoreline-indicator plants are rare. Those that are present are not authigenic and were likely transported to the deeper waters. This suggests that deep-water, offshore conditions persisted for the past 1100 years, and is consistent with interpretations made by Telka (2000). Below a depth of approximately 20 cm, there are no apparent changes in either macrofossil abundance or diversity, indicating that paleoenvironmental factors remained relatively constant during this period.

Pre-twentieth century trends in mayfly, ostracode and flatworm abundance, observed in both cores, may indicate gradual changes in ecosystem dynamics.

Evidence of floods

Flood deposits might be expected to contain a higher concentration of terrestrial macrofossils, from the rapid influx and deposition of terrestrial material that might be expected to accompany a flood. The occurrence of layers with a higher concentration of terrestrial material was not observed in the offshore Lake Winnipeg sediments. Terrestrial material occurs only sporadically throughout the two cores and not as correlateable layers. The reason for this is likely because the occurrence of this material diminishes with increasing distance from the shoreline. Also, assuming that flood events would commonly consist of layers less than 5-cm thick, the larger 5-cm sampling interval would reduce macrofossil concentrations. Other factors, such as flood dynamics and basin geometry, may also be partially responsible.

Anthropogenic effects

The two- to three-fold increases in the number of macrofossil identifications at the tops of the cores are likely due to nutrient influx caused by anthropogenic processes. The alternative of post-burial deposition is not corroborated by a gradual pre-twentieth century decline in abundance or by the presence of partially decomposed macrofossils. In particular, the observed increases in resistant Chironomidae remains, unlikely to undergo gradual decomposition, can be attributed to increases in nutrient levels. Chironomidae concentrations have been used as indicators of water quality and eutrophication and have shown that eutrophication of lake waters is associated with a rapid increase in the relative abundance of *Chironomus* spp. (e.g. Warwick, 1980; Brodin, 1982; Wiederholm and Eriksson, 1979). Increases were observed in the top 20 to 30 cm, indicating that the onset of eutrophication was between AD 1874 and AD 1934. Higher nutrient levels have also been inferred in Lake Winnipeg by Kling et al. (2002) and Stainton et al. (2002). Kling et al. (2002) found that increased nutrients and changes in the flow and light regimes have caused increases in phytoplankton biomass and changes to species diversity in the past century. Stainton et al. found that increases in algal productivity are predominantly from nitrogen-fixing blue-green algae. Enhanced phosphorous concentrations were also observed in the upper 20 cm or so of the lake-bottom sediments (Simpson and Thorleifson, this volume; Mayer et al., this volume).

Evidence of fires

Intervals of enhanced abundance of charred remains in core 9 perhaps represent periods of fire occurrences in the watershed. The dates of fire occurrence have been estimated by correlation with dated core 8 (Wilkinson and Simpson, this volume) and are given as ranges, corresponding to 5-cm intervals (AD 1912-1929, 1429-1461 and 1024-1056).

CONCLUSIONS

- The macrofossil record for the offshore cores is dominated by aquatic insects and crustaceans, with a much smaller proportion of shoreline and terrestrial macrofossils, indicating that deep-water conditions persisted for the past 1100 years and that minimal transport of terrestrial material to deeper waters has occurred.

- The macrofossil record does not show evidence of incoming pulses of terrestrial material that could be attributed to floods.

- Increases in macrofossil abundance, comprised significantly of Chironomidae, in the top 20 to 30 cm of the cores, suggests that the eutrophication of lake waters during deposition of the 5-cm interval that spans about AD 1874 and AD 1934.

- The occurrence of intervals rich in charred remains suggests that major fires occurred in the watershed in AD 1912-1929, AD 1429-1461 and AD 1024-1056.

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Table 1. Faunal macrofossils recovered from Lake Winnipeg 99-900 core 7

Taxa	*	Depth (cm)																													
		0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-105	105-110	110-115	115-120	120-125	125-130	130-135	135-140	140-145	145-150
Aquatic and shoreline taxa																															
PLATYHELMINTHES																															
TUBELLARIA "flatworms" (cocoons)	a		36	37	24	15	13	7	4	2	6	10	10	6	14	4	12	7	5	8	6	20	18	14	18	8	10	6	16	22	10
ANNELIDA																															
HIRUDINEA "leeches" (cocoon)	a					1																									1
ARTHROPODA																															
INSECTA																															
EPHEMEROPTERA "mayflies"(immatures)	a		11	15	13	14	12	12	8	3	13	6	8	10	5	3	6	4	7	7	6	13	19	6	7	5	14	6	9	12	4
HEMIPTERA "bugs"					1																										
Corixidae "water boatmen"	a							1				1			1				1			1		1	1		1				1
COLEOPTERA "beetles"																															
Carabidae "ground beetles"																															
Bembidion sp.	s			1			1																			?1			1		
Hydrophilidae "water scavenger beetles"	a/s														1												1			1	
Helophorus sp.	a/s		1											1																	
Hydraenidae "minute moss beetles"	s				1																										
Ochthebius sp.	s		1				1						1							1			1							1	
Staphylinidae "rove beetles"																															
Olophrum consimile Gyll.	s																					1									
Stenus sp.	s																	1					1								
Helodidae "marsh beetles"	s			1	1	1	1																1				1			1	
Cyphon sp.	s				?1	?1																									
DIPTERA "flies"																															
Chironomidae "midges" (immatures)	a		102	99	34	25	8	14	4	9	9	24	7	8	9	3	20	8	10	7	5	8	10	13	6	9	18	4	14	11	45
CRUSTACEA																															
Cladocera "water fleas"																															
Daphnia sp. (ephippia)	a		394	193	191	69	68	171	44	50	61	55	56	71	59	87	78	56	68	60	29	45	71	55	55	29	116	68	68	58	193
Ostracoda "ostracodes" (valves)	a		27	2	1			3	4	6	5	1	6	2	4	4	24	15	3	11	19	8		4	5		3			1	9
ARACHNIDA																															
Araneae "spiders"	a/s		1																									1	2		
MOLLUSCA							fr2		fr1	fr3								fr4			fr5							fr1			
Gastropoda "snails, limpets"	a																fr1														
Pelecypoda "clams, mussels"	a		fr6	fr8					fr6	fr3	fr3	fr1					fr4					1					fr3				fr5
Unidentifiable animal taxa:			1			1														1			1			fr1					
fish vertebra(e)/bone	a		6	2	1			1			1			1				1			2		1				1	1	1	3	2
fish scale	a		1							fr3																	1			1	
immature soft-bodied insects	a		+	2	4	9	22		1		2		3	2	3								10								5

***Habitat designation: a=aquatic; a/s=aquatic to shoreline; s=shoreline. fr=fragment; +=taxon present; ?=questionable identification.**

Table 1 continued

Taxa	*	Depth (cm) 0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-105	105-110	110-115	115-120	120-125	125-130	130-135	135-140	140-145	145-150
Terrestrial taxa																															
ARTHROPODA																															
INSECTA			1		1			1	1				1		1	1		1	1	2			3	1			1				1
HEMIPTERA "bugs"													1								1						1				
HOMOPTERA "cicadas, hoppers, aphids"																															
Cicadellidae "leafhoppers"	t									1											1						1	1			
Psyllidae "jumping plant lice"	t												1									1									
COLEOPTERA "beetles"							1	1							1		1			1		1									
Carabidae "ground beetles"	t				1					1	1																				
Staphylinidae "rove beetles"	t		2	3	1														1	2				1			1	1		1	
Micropeplus tesserula Curtis	t			1																								1			
Tachyporus sp.	t				1																										
Aleocharinae	t			1															1	1					2						
Ptiliidae "feather-winged beetles"	t																								1						
Scydmaenidae "ant-like stone beetles"	t																										1				
Scarabaeidae "scarab beetles"	t			1																											
Lathridiidae "minute scavenger beetles"	t			1																							1				
Chrysomelidae "leaf beetles"	t			1								1	?1																		
Curculionidae "weevils"	t		1																												
LEPIDOPTERA "butterflies/moths"																													1		
DIPTERA "flies"			5			1			1			3		4	1		2				1		4		2	1	4	2	3		2
HYMENOPTERA "wasps and ants"			3	2	5		3	4	1				1	1		1	5	1	2	3	3	4	2			1	1	1	5	4	3
Braconidae	t																														
Cheloninae	t											1																			
Ichneumonidae	t							1									2								2						
Formicidae "ants"	t							1													2		1								
ARACHNIDA																															
Oribatei/Acari "mites"	.																0.5														

***Habitat designation: t=terrestrial. ?=questionable identification.**

Table 2. Floral macrofossils recovered from Lake Winnipeg 99-900 core 7

Taxa	*	Depth (cm)																													
		0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-105	105-110	110-115	115-120	120-125	125-130	130-135	135-140	140-145	145-150
Aquatic taxa																															
Bryophytes "mosses"	a/s												fr1		fr5																
Typhaceae "Cat-tail family"																															
Typha sp.	ae								1						1				1	1		1	2		1	1				3	
Alismataceae "water plantain family"																															
Alisma sp.	ae						1																								
Haloragaceae "water milfoil family"																															
Hippuris sp.	a					1																									
Apiaceae "parsley family"																															
Cicuta sp. "water hemlock"	a									0.5																					
Shoreline and terrestrial taxa																															
Poaceae "grass family"	s/t													?1	?1																
Juncaceae "rush family"																															
Juncus/Luzula type	s/t																1														
Polygonaceae "buckwheat family"																															
Rumex sp.	s/t			0.5																											
Ranunculaceae "crowfoot family"																															
Ranunculus sceleratus type	s/t																													1	
Rosaceae "rose family"																															
Potentilla sp.	s/t																					1									
Onagraceae "evening primrose family"																															
Epilobium sp.	s/t																								1.5						
Lamiaceae "mint family"																															
Lycopus sp.	s/t																											1			
Asteraceae "Composite family"	s/t		0.5																?1												
Taraxicum sp. "dandelion"	s/t		2																												
Circium sp. "thistles"	s/t			2																											

***Habitat designation: a=aquatic; ae=aquatic emergent; s/t=shoreline to terrestrial; a/s=aquatic to shoreline. fr=fragment; ?=questionable identification.**

Table 2 continued

Taxa	*	Depth (cm) 0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-105	105-110	110-115	115-120	120-125	125-130	130-135	135-140	140-145	145-150
Trees and other																															
Pinaceae "pine family"																															
Larix laricina (DuRoi)Koch.	tr														fr1																
Picea sp.	tr												fr1																		
Unidentified plant taxa:				1			1						fr1																		
Charcoal and non-biogenic (fragments):																															
charcoal/charred organics					+		+	+				+		+	+								+						+	+	
plastic																														9	9
metal shavings, aluminum																														1	2
vivianite																						3									

***Habitat designation: tr=tree (terrestrial). fr=fragment; +=material present.**

Table 3. Faunal macrofossils recovered from Lake Winnipeg 99-900 core 9

Taxa	*	Depth (cm)																											
		0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-105	105-110	110-115	115-120	120-125	125-130	130-135	135+
Aquatic and shoreline taxa																													
PLATYHELMINTHES																													
TUBELLARIA "flatworms" (cocoons)	a	23	54	48	28	24	23	10	6	12	9	9	25	14	11	9	3	18	11	10	16	16	26	32	34	43	13	18	12
ARTHROPODA																													
INSECTA:																													
EPHEMEROPTERA "mayflies"(immatures)	a	28	22	53	43	38	60	24	20	27	22	11	19	10	7	6	15	25	14	6	29	6	14	37	17	34	9	34	23
HEMIPTERA "bugs"											1																		
Corixidae "water boatmen"	a					1	1					1					1		1	1							1		
Saldidae "shore bugs"	s												1																
COLEOPTERA "beetles"																													
Dytiscidae "predaceous diving beetles"	a			1									1										1		1?				
Hydrophilidae "water scavenger beetles"	a/s											1															1		
Hydraenidae "minute moss beetles"	s			1	1	1																						1	
Ochthebius sp.	s										1						1								1				
Staphylinidae "rove beetles"																													
Olophrum sp.	s							1							1				1										
Helodidae "marsh beetles"	s							1										1			1	1	1	1					
TRICHOPTERA "caddisflies" (immatures)	a	1	1			2																							
DIPTERA "flies"																													
Chironomidae "midges" (immatures)	a	157	177	125	73	24	26	22	20	28	18	7	21	7	18	15	8	12	14	14	17	10	15	25	6	11	16	19	6
Chaoboridae "phantom midges" (immatures)	a																								1?				
CRUSTACEA:																													
Cladocera "water fleas"																													
Daphnia sp. (ephippia)	a	358	568	467	358	224	293	165	133	159	129	91	191	84	140	120	118	125	121	89	117	103	93	119	225	71	115	126	82
Ostracoda "ostracodes" (valves)	a	104	109	64	7	14	28	21	59	19	11	2	4	6	7	11	17	19	28	49	14	13	5	15	3	12	17	16	4
ARACHNIDA:																													
Araneae "spiders"	a/s								1																				
MOLLUSCA																													
Pelecypoda "clams, mussels"	a	5fr	5fr	7fr	8fr	3fr	4fr	3fr	3fr	5fr	2fr	2fr	5fr			1fr	3fr	4fr	3fr	3fr									10fr
Unidentifiable animal taxa:									1																				
Other:																													
fish vertebra(e)/bone	a		1			1	1		2				1						1	1?									
fish scale	a		1fr				2fr	2fr								1												1	
egg cases/cocoons	a			1			1	1						1	1														
immature soft-bodied insects	a	38	35	42	20	30	35	17	17	19	10	9	14	9	8	5	1	17	5	7	11	10	7	10	13	6	4	12	17

***Habitat designation: a=aquatic; s=shoreline; a/s=aquatic to shoreline. fr=fragment; ?=questionable identification.**

Table 3 continued

Taxa	*	Depth (cm)																											
		0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-105	105-110	110-115	115-120	120-125	125-130	130-135	135+
Terrestrial taxa																													
ARTHROPODA																													
INSECTA:																													
HEMIPTERA "bugs"																												1	1
Tingidae "lace bugs"	t							1																					
HOMOPTERA "cicadas, hoppers, aphids..."																									1				
Cicadellidae "leafhoppers"	t															1												1	
Psyllidae "jumping plant lice"	t																								1				
COLEOPTERA "beetles"																													
Carabidae "ground beetles"	t				1								1																
Staphylinidae "rove beetles"	t	1	2	2									1			1								1	1	1	1	1	1
Aleocharinae	t			1					1	2	1							1		1	1				1			1	
Scarabaeidae "scarab beetles"										1															1				
Aphodius sp.	t																							1					
Byrrhidae "pill beetles"	t			1			1						1							1									
Elateridae "click beetles"	t																							1					
Lathridiidae "minute brown scavenger beetles"	t					1				3																1			
Chrysomelidae "leaf beetles"	t																					1			1				
Curculionidae "weevils"	t															1?													
LEPIDOPTERA "butterflies/moths"													1												1				
DIPTERA "flies"			10	11		5	1	3	6	5	3	2	3	1	2	1		2	2	2		1	2	2	3	1	1	4	1
Bibionidae "march flies"	t			1			1																						
HYMENOPTERA "wasps and ants"		1	3	1	1	1	1	1	2	3	1		2			1	2		2	1	1	1	2		3	2	4	1	2
Ichneumonoidea	t	2	1	1	1		1	2			2			1	2										1		1	1	2
Ichneumonidae	t		1	1		1	1		1			1	1									1	1				1		
Formicidae "ants"	t								1											1									
ARACHNIDA:																													
Oribatei/Acari "mites"																		1							0.5				

***Habitat designation: t=terrestrial. ?=questionable identification.**

Table 4. Floral macrofossils recovered from Lake Winnipeg 99-900 core 9

Taxa	*	Depth (cm)																											
		0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-105	105-110	110-115	115-120	120-125	125-130	130-135	135+
Aquatic taxa																													
Bryophytes "mosses"	a/s				2	4					1		3	1				3	1	1						1		2	
Typhaceae "Cat-tail family"																													
Typha sp.	ae	4	1		1	2	2	2			1	1						2	1	1								2	
Haloragaceae "water milfoil family"																													
Hippuris sp.	a				1																								
Shoreline and terrestrial taxa																													
Poaceae "grass family"										1																			
Poa sp.	s/t														1?														
Cyperaceae "sedge family"																													
Eleocharis sp.	s/t																									1			
Violaceae "violet family"																													
Viola sp.	s/t																							1					
Onagraceae "evening primrose family"																													
Epilobium sp.	s/t			1																									
Asteraceae "composite family"				1															1			1						1	
Circium sp. "thistles"	s/t		1																										
Trees and other																													
Pinaceae "pine family"							1																						
Larix laricina (DuRoi)Koch.	tr						1fr																						
Pinus sp.	tr									1fr																			
Picea sp.	tr							1fr						1fr												1fr			
Unidentified plant taxa:																1													
Charcoal and non-biogenic (fragments):																													
charcoal/charred organics				2	48	106	69	18	22	12	5	9	21	11	1	1	6	271	8		6	3			2	5	82	793	103
plastic		16																											4
vivianite																					1				3	3			

***Habitat designation: a=aquatic; ae=aquatic emergent; s/t=shoreline to terrestrial; a/s=aquatic to shoreline; tr=tree (terrestrial). fr=fragment; ?=questionable identification.**

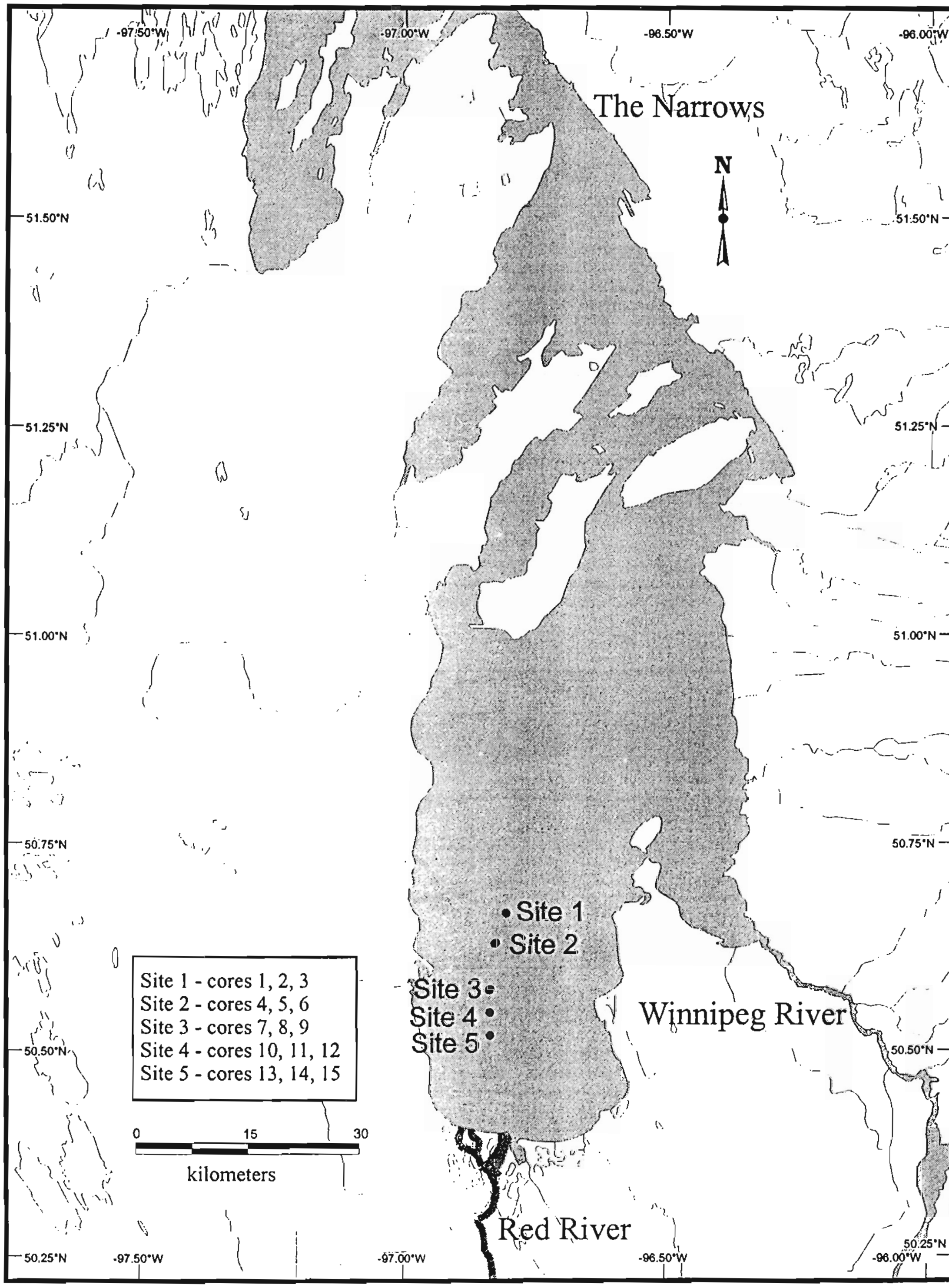

Figure 1. Map of southern Lake Winnipeg showing locations of coring sites

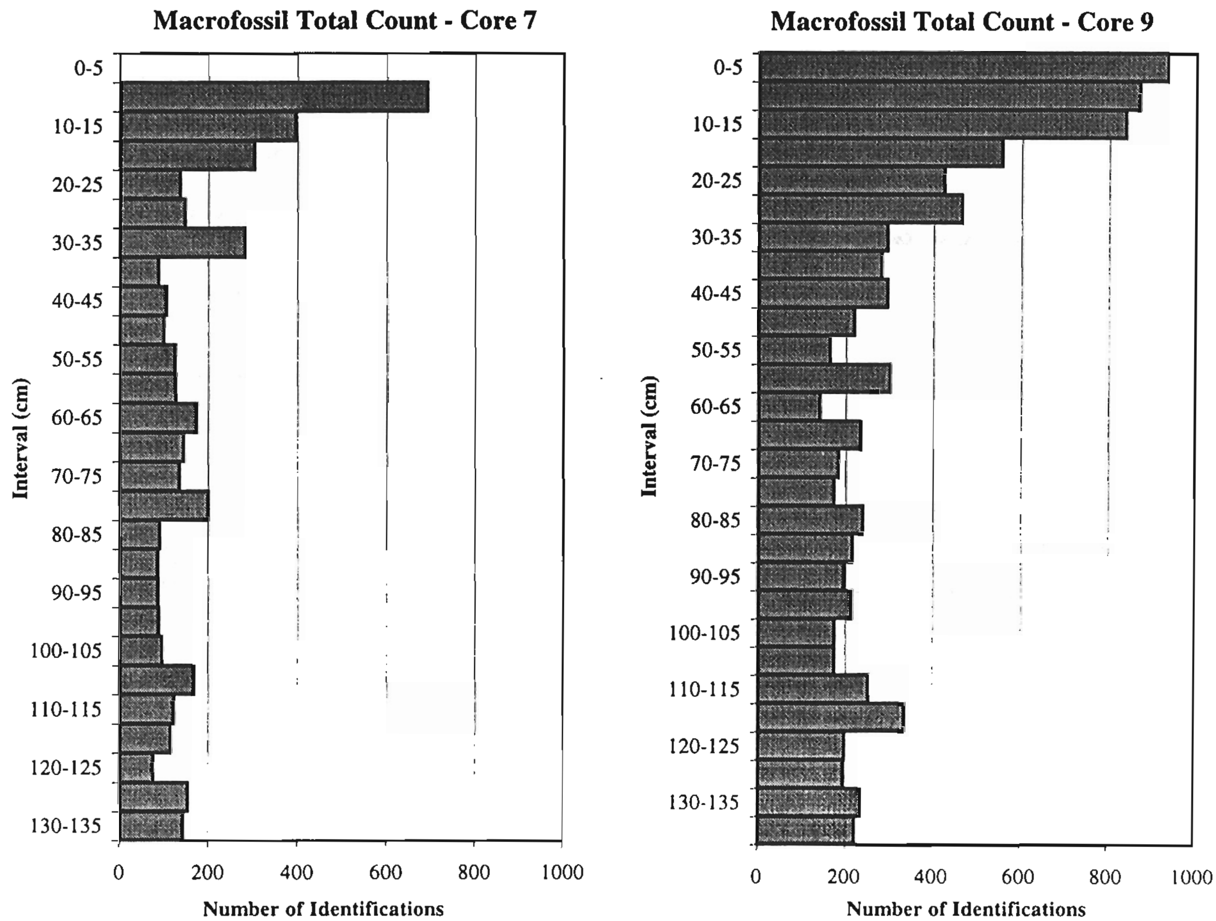

Figure 2. Down-core variations in macrofossil abundance in Lake Winnipeg 99-900 cores 7 and 9. Analyses of the top 5 cm of core 7 were disregarded due to a mixing error.

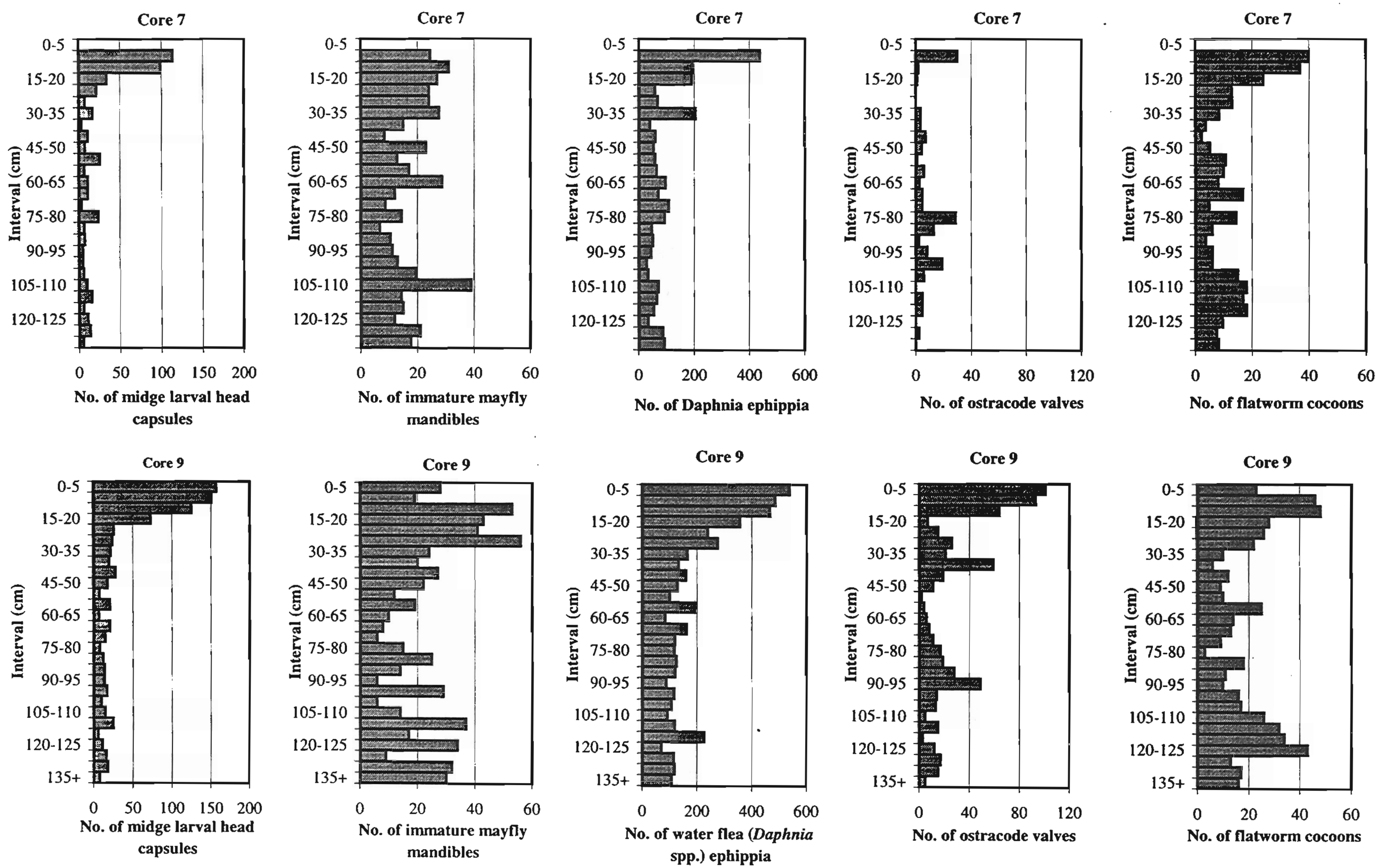

Figure 3. Down-core variations in abundance of dominant macrofossil taxa in Lake Winnipeg 99-900 cores 7 and 9. Analyses of the top 5 cm of core 7 were disregarded due

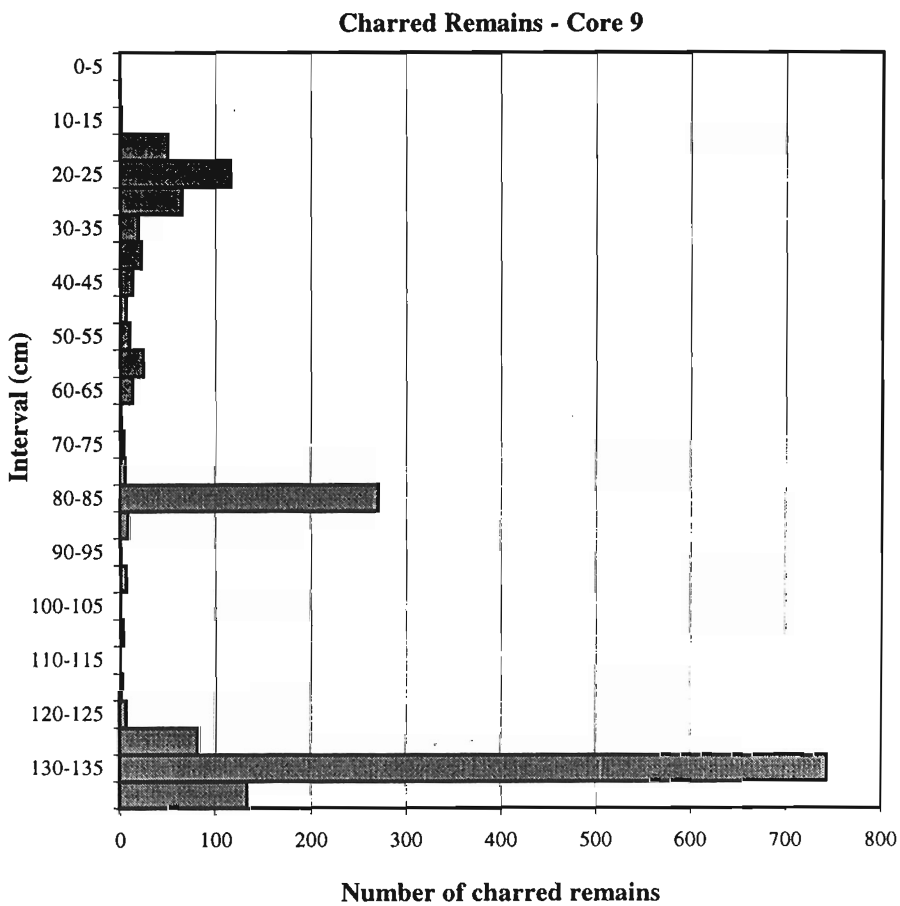

Figure 4. Down-core variations in abundance of charred remains identified in Lake Winnipeg 99-900 core 9

6.2 Palynological analysis of Lake Winnipeg 99-900 cores 3, 4 and 8

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ABSTRACT

**Following the 1997 Red River flood, research addressing the history and controls on the flood hazard included analysis of sediments in Lake Winnipeg to assess flood history and drainage basin evolution. To do so, 15 cores, each about 1.5 m long, were collected from the south basin during a cruise of the Canadian Coast Guard Ship (CCGS) Namao in August 1999, designated Geological Survey of Canada (GSC) cruise 99-900.* Pollen analysis of an entire core was completed to aid dating, correlation, and paleoenvironmental analysis. Additional pollen and diatom analyses of select strata in two additional cores were completed after preliminary interpretations had been made, in order to enhance core chronology, facilitate core-to-core correlation, and corroborate initial interpretations. The cored sediments are attributed approximately to the past 1100 years on the basis of radiochemistry, paleomagnetic analysis, palynology and radiocarbon dating. A mixture of boreal forest and grassland/parkland taxa dominates the entire record. A basal pollen assemblage zone (zone 3) is dominated by *Pinus* (pine); a middle zone (zone 2) is distinguished by upward-decreasing percentages of *Pinus* and upward-increasing percentages of *Picea* (spruce); and an upper zone (zone 1) is characterized by more abundant weed and grass pollen. The increase in *Picea* and decrease of *Pinus* at the zone 3/2 boundary, dated at ~ AD 1100 based on the age model constructed from radiochemical, radiocarbon and paleomagnetic dates, is indicative of a cooler climate and is interpreted as the onset of the Little Ice Age. The zone 2/1 boundary is best marked by the first sustained appearance of *Salsola*, occurring at 27 cm depth in cores 3 and 4 and 28 cm depth in core 8. Based on Pb-210 this marker is dated at ~1895, which agrees reasonably well with the probable timing for the arrival of *Salsola* pollen to Lake Winnipeg, about AD 1888 based on records of the first appearance of *Salsola* at the headwaters of the Red River. The increase in weed and grass pollen at this boundary is interpreted as the beginning of extensive agricultural development of the lower Red River Valley. *Alnus* (alder) and *Salix* (willow) cycles were observed throughout the record, but do not correlate core to core. Preliminary diatom analyses within and between layers of enhanced silt lacked differences and could not be used to provide an environmental interpretation of the silt layers. The lack of differences is attributed to the high siliciclastic content of the samples that hindered diatom analysis.

INTRODUCTION

The Red River flood of 1997 was a major disaster that drove 103,000 people from their homes. Much is being done, however, to reduce comparable damage and disruption in the future through enhanced dikes and diversions, as well as revised land use and water management practices. The design of these works requires an optimal understanding of the risk. Research therefore has addressed the nature of the largest known flood, in 1826, whether comparable large floods have occurred in recent centuries, and how geomorphic, climatic, land use, and tectonic factors may be changing the flood hazard. These issues are being addressed by examining the geomorphic processes governing evolution of the Red River, archival records of flood history, floodplain stratigraphic records, tree-ring records, changes in valley gradients, and by examining the stratigraphy of Lake Winnipeg sediments (Thorleifson et al., 1998). The coring in Lake Winnipeg, receiving basin of waters from the Red River, was designed to sample sites most likely to have recorded any influx of sediments from the Red River that may have occurred. In addition to recording gradual changes in Red River sediment transport, it was thought that flood events might be recognizable, due to unique properties allowing differentiation from other sediments in the lake, although it was unclear what attribute would best distinguish flood-related sediments. The cores therefore were thoroughly analyzed for chronology, as well as for a broad range of physical, chemical and biological properties to determine which, if any, would record a history of flooding.

Micropaleontological analysis of palynomorphs, both pollen and spores, is a valuable contributor to paleolimnological research due to excellent preservation, straightforward preparation, ability to distinguish a broad range of taxa, and provision of information on both terrestrial and aquatic vegetation history from which inferences may be made with respect to climate, landscape modification, invasions and local extinctions, and nutrient status (Birks and Birks, 1980; Birks, 1981). These inferences not only reveal basin history, but also provide chronological markers. In the case of this study, the aim was to prepare a complete pollen profile for a core to infer vegetation history for Lake Winnipeg south basin sediments representing the last millennium. It was anticipated that the resulting profiles could be examined for possible evidence of climatic variability, and to establish horizons and ages

* Italicized text is repeated in each chapter

for development of extensive agriculture. Partial pollen profiles at a second and third site were completed to enhance core chronology and to facilitate core-to-core correlation.

It was thought that diatom analysis might corroborate initial interpretations on the origin of silt layers identified throughout the cores (Simpson and Thorleifson, this volume), as diatoms have been used successfully in other lakes to reconstruct flood records (Hay et al., 1997; Hay et al., 2001; Michelutti et al., 2001) because they inhabit a wide range of environmental niches including soil, lake, river and marine setting, and many species are unique to specific environments. As Medioli and Brooks (*in press*) characterized the diatom signatures of Red River floods in 1997 and 1999, and diatom assemblages in other lakes have been characterized, diatom analysis of Lake Winnipeg sediments could potentially provide information on the timing and perhaps severity of Red River flooding.

LAKE WINNIPEG

Lake Winnipeg, located in central North America, is the eleventh largest lake in the world, having an area of 24,000 km^2 (Hutchinson, 1975). The lake straddles the contact between Paleozoic carbonate rocks to the west and Precambrian igneous and metamorphic rocks of the Canadian Shield to the east. A smaller south basin, approximately 90 km by 40 km, is separated from a north basin, approximately 240 km by 100 km, by a narrow passage known as The Narrows. The glacially-scoured depression in the rocks underlying the lake, with a depth of 50-100 m, is largely filled with fine-grained glacial Lake Agassiz sediments, overlain by up to 15 m of post-glacial Lake Winnipeg sediments (Todd and Lewis, 1996). The bathymetry of the lake is shallow and the bottom is flat, with depths averaging 9 m in the south basin and 16 m in the north basin. The lake has a catchment area extending from the Rocky Mountains to very near Lake Superior, including the basins of the Winnipeg, Saskatchewan, Red, Dauphin and numerous smaller rivers. Outflow from the lake is north to Hudson Bay, through the Nelson River. Post-glacial uplift has caused the north end of the basin to rise relative to the south, causing a gradual rise of lake levels that continues at present (Lewis et al., 2000). The mean annual temperature of the region, recorded at Gimli, is +1.4°C, although the continental climate of the region ranges from hot summers to very cold winters. The mean annual precipitation is 50.8 cm. The lake is ice free from early May to late November (Ice Thickness Climatology, 1992) and ice cover from November to May is consistently thick and continuous. The lake waters are poorly stratified to unstratified and during the summer months water temperatures range from +17°C in the north basin to +19.5°C in the south basin (Todd, 1996), hence bottom sediment temperatures are equally warm in mid-summer. The lake supports a commercial fishery, it is a major destination for recreation, and lake levels are regulated to optimize hydroelectric power generation on the Nelson River.

SAMPLING AND ANALYTICAL METHODS

Selection of five sampling sites in the south basin of Lake Winnipeg was based on proximity to the Red River mouth and on the absence of ice scour on sidescan sonar records previously obtained in 1994 on the 94-900 Namao cruise (Lewis et al., this volume) (Figure 1). Site 5 was the southernmost point on the north-south survey line that lacked ice scour. Sampling was conducted in calm weather on August 24, 1999 from the CCGS Namao. Three cores were obtained at each of the five sites using a gravity corer consisting of a 100 kg weightstand over a 2 m steel pipe with a 10 cm diameter plastic liner tube. The length of the cores ranged from 107 cm to 170 cm. The cores were sealed, labelled and transported to Gimli, Manitoba on August 29, where they were refrigerated, and subsequently transported via refrigerated truck to the GSC Atlantic core storage facility in Dartmouth, N.S. A monitoring device attached to the core bundle indicated that the sediments did not exceed a temperature of 19°C at any time during transport. Paleomagnetic and physical property data, determined at the laboratory of Professor J.W. King at the University of Rhode Island, provided information used to select cores that would be representative of the offshore sediments (King et al., this volume). Paleomagnetic profiles indicated more rapid accumulation of sediments at the more northerly sites and hence a higher resolution for examining environmental change. Based on these observations, core 8 (site 3), core 4 (site 2) and core 3 (site 1) were selected as the primary records for detailed study.

A total of 41 samples 1 cm^3 in size were obtained from core 8 at GSC facilities in Dartmouth. A list of the samples microscopically examined and comprising the pollen diagrams is shown in Table 1. The samples were obtained at 4-cm intervals for much of the core, and at 2-cm intervals for the portion of the core thought to represent the period of anthropogenic impact (12-38 cm). Due to financial considerations, some sections thought to consist of a monotonous composition were sampled at a coarser interval. Palynological analysis was also undertaken on samples 1 cm^3 in size from the upper 45 cm of core 4 and the 21-35 cm depth interval for core 3, the range most likely to record increases in pollen associated with the beginning of extensive agriculture (zone 2/1 boundary). A list of the samples from cores 3 and 4 microscopically examined and comprising the pollen diagrams is given in Table 2. The samples were obtained at 2-cm intervals for core 3 and 2- to 8-cm intervals for core 4.

Selected samples were prepared by acid digestion with HF and HCl followed by acetolysis. Known concentrations of *Lycopodium* were added to each sample during the preparations to compute pollen concentrations (grains/cm^3).

The treated samples were then identified and tabulated. A minimum of about 220 tree, shrub and herb pollen grains constitute the pollen sum (excluding Cyperaceae and pollen of aquatic plants), which represented the basis for calculating pollen percentages. Pollen diagrams were drafted with the computer programmes TILIA and TILIA-GRAPH (Grimm, 1991).

Preliminary diatom analyses were conducted on nine samples, five of which were sampled from layers of greater silt content, and four of which were sampled from between these layers (Table 3). The samples were digested with acid to remove non-siliceous material, and subsequently examined microscopically.

RESULTS

Complete pollen record

A complete pollen record was obtained for core 8. Examination of a plot showing all identified pollen taxa (Figure 2) or an abbreviated plot showing only key taxa (Figure 3), indicates that the pollen record is dominated by both boreal forest taxa (*Picea, Pinus, Betula, Alnus, Salix*) and grassland/parkland taxa (*Ambrosia, Artemisia*, other Compositae, Gramineae, Chenopodiineae). The profile is divisible into three pollen assemblage zones.

Zone 3 (base of core – 136 cm) is differentiated on the basis of maximum *Pinus* percentages. *Picea*, deciduous hardwoods and grassland/parkland taxa are at minima. *Alnus* reaches maximum values close to 15%.

Zone 2 (136 cm – 28 cm) is the pre-extensive agriculture zone and is distinguished by upward-decreasing percentages of *Pinus* and upward-increasing percentages of *Picea*. *Artemisia*, Ambrosia, other Compositae, Gramineae and Chenopodiineae are the grassland/parkland indicators, but as in the previous zone, the herb percents are consistently low throughout the zone. *Betula, Populus, Quercus* and other deciduous taxa are slightly higher than in zone 3. Cyperaceae, like *Picea*, is at its maximum in this zone. *Alnus* is inconsistent as it varies from less than 5% to almost 15%.

Zone 1 (28 cm – core top) is the extensive agriculture zone, based on the first appearances of *Salsola, Brassica* and *Rumex*, and significant increases in *Ambrosia*, the chenopods, and Gramineae. The weed and grass pollen increases are reflected by a noticeable increase in the total herb profile. *Picea* remains unchanged from the previous zone whereas *Pinus, Alnus* and Cyperaceae decrease slightly towards the top of the zone.

Partial pollen records

Abbreviated pollen diagrams for the upper 45 cm of cores 3, 4 and 8 are shown in Figures 4, 5 and 6, respectively, and complete pollen diagrams for this interval are shown in Figures 7, 8 and 9, respectively. Pollen profiles for cores 3 and 4 are very similar to that obtained for the upper portion of core 8. At the tops of the cores first appearances of *Salsola, Brassica* and *Rumex*, and significant increases in *Ambrosia*, the chenopods, and Gramineae (*Avena, Triticum, Secale* type) define the zone 2/1 boundary and occur at similar depths in all three cores. The first sustained occurrence of *Salsola* appears consistently in the three cores at depths of 27 cm in cores 3 and 4 and 28 cm in core 8.

Alnus (alder) and *Salix* (willow) cycles are evident in cores 4 and 8, although the trends are dissimilar in each of the two cores (Figure 10).

Diatom record

Preliminary diatom analyses within and between layers of enhanced silt in core 3 lacked differences, although the high siliciclastic content hindered analysis. The diatoms were characterized by small numbers of Aulacoseira, typical of shallow, well-mixed lakes. Because of the lack of differences observed in the preliminary analysis and the high siliciclastic content of the sediments, it was decided that more detailed diatom analysis would likely not yield useful paleoenvironmental information.

DISCUSSION

Pollen assemblage Zones

The increase in *Picea* and compensating decrease of *Pinus* at the zone 3/2 boundary, dated at about AD 1100 (Wilkinson and Simpson, this volume), is indicative of a change to cooler climatic conditions. The age of this cooling differs somewhat from estimations for the onset of the Little Ice Age in North America, at AD 1430 (Gribbin and Lamb, 1978). During the Little Ice Age, temperatures averaged 1-3°C less than today. The occurrence of Little Ice Age, well documented and dated in Europe, is not as well characterized for the prairie region of Canada, hence, local palynological information can be useful in refining age estimates of this event in the region. Based on the persistence of *Picea* to near the top of zone 2, at about 42 cm, the cooling trend continued until the late 18th century, slightly earlier than the global termination of the Little Ice Age at AD 1850 (Gribbin and Lamb, 1978). Hence, the cooling event known as the Little Ice Age in other areas of the world appears to have begun and ended earlier in the Canadian Prairies.

First appearances of *Salsola, Brassica* and other crucifers, *Rumex*, cereal grasses (*Avena, Triticum, Secale* type) and increased percentages of the composites (notably *Ambrosia*) and chenopods at the 2/1 boundary, dated at about AD 1888 by radiochemical methods (Wilkinson and Simpson, this volume), mark extensive settlement and the time of extensive agricultural development in the lower Red River valley. These taxa took advantage of soil disturbances and thrived in the new environments created by increased acreage under cultivation when the population of southern Manitoba increased 4-fold between AD 1881 and 1900 (Statistics Canada, 1986). The year AD 1881 marked the opening of the railroad that linked the wheat-growing region around Winnipeg with shipping outlets on the Great Lakes.

The zone 2/1 boundary is best marked by the abrupt increase of *Salsola* pollen. The increase in *Salsola* provides an additional chronological marker for the cores and a means of verifying Pb-210 ages. The pollen evidence could be that of either *Salsola iberica* or *S. paulsenii* or both. *S. kali* appears to be synonymous with *S. iberica* (Beatley, 1973). *Salsola iberica* appears for the first time in the pollen record at Devils Lake, North Dakota at AD 1894-1895 based on Pb-210 dating (Jacobson and Engstrom, 1989). The earliest observations of plants of *Salsola kali* in southern Manitoba were reported in 1895 (Dewey, 1895).

Salsola (Russian Thistle) produces large quantities of pollen, and like most taxa of the Chenopodiineae, its pollen is easily dispersed and can occur several to tens of kilometers from the source. *Salsola* seeds are dispersed predominantly by wind and via the railway (transported in flaxseed). The small roots of *Salsola* tend to break during forceful winds, causing the plant to tumble and the seeds to disperse. The corolla attached to the seed acts like a sail and consequently the seeds are carried by the wind. Individual plants have been estimated to advance at a rate of 8 to 15 km per season over flat terrain, primarily in the direction of the prevailing winds (Jacobson and Engstrom, 1989).

The first arrival of *Salsola* at Devil's Lake, North Dakota occurred in 1895. Given that this lake is about 260 km south of Lake Winnipeg, and that northerly transport rates have been estimated at 55 km/year (Jacobson and Engstrom, 1989), it seems reasonable that *Salsola* would have reached the Lake Winnipeg area within 5 years of its arrival at Devil's Lake.

First occurrences of *Salsola kali tragus* in southern Manitoba occurred in 1895, as documented and mapped by Dewey (1895). Mapping was based on reported occurrences of the plant over a 3-year period, hence, any occurrences within the 3 years prior to 1895 were lumped as 1895. Hence, *Salsola* was in the region by 1895 and possibly as early as 1892. Given the rapid pollen dispersal rate of 55 km/year, *Salsola* would require no more than 2 years to reach the southernmost point in Manitoba.

However, *Salsola* pollen may have been fluvially deposited in Lake Winnipeg as early as 1888. *Salsola* plants arrived in northeast South Dakota around 1886-1888 and in the southeastern Counties of Dickey, La Moure and Stutsman, North Dakota, between 1888 and 1891 (Jacobson and Engstrom, 1989). These Counties are located proximally to the head tributary area of the Red River in southeast North Dakota. Assuming instantaneous fluvial transport, *Salsola* pollen could have reached Lake Winnipeg by as early as 1888. The date AD 1888 is therefore the best estimate for the age of the zone 2/1 boundary and increase in *Salsola* at 28 cm depth. This estimate corresponds favourably with the chronology derived from Pb-210 dates of AD 1895 at the 28-29 cm depth (Wilkinson and Simpson, this volume).

Increases in pollen concentration across the zone 2/1 boundary reflect a real increase in upland weeds and cereal grasses associated with extensive agriculture (Figures 2 and 3). Overall pollen concentrations are highest at the percentage peaks of *Ambrosia, Salsola* and *Brassica*. The percentage maxima of these taxa (18-22 cm) are sequentially followed by maxima in cereal grasses and chenopods. The peak, and subsequent decline, in cereal grasses may relate to the acreage of land devoted to wheat having reached its peak by the mid-1970's.

Cycles in the *Alnus* and *Salix* profiles

Alnus fluctuates from about 5% to above 10% from top to bottom. *Salix*, likewise, varies between 5% and 10%. Exaggerating the x-axis of the *Alnus* and *Salix* curves (Figure 10) accentuates the peaks and valleys of the profiles defined by multiple samples. For *Alnus*, in particular, a peak-valley pattern becomes apparent. There is no clear correlation of the *Alnus* and *Salix* peaks and valleys except perhaps for the peaks at the zone 2/1 boundary.

The *Alnus* pollen closely compares with the species *Alnus rugosa* (speckled alder), which is the common alder of most wetland sites such as stream banks and swamps (Farrar, 1995). Speckled alder has potential as an indicator of site quality because it grows vigorously where tree growth is good but is less vigorous and not as common in areas where tree growth is poor (Vincent, 1964). The alders and willows are known for their tolerance to temporary flooding (Hall and Smith, 1955). Experiments have shown that speckled alder and willow are also tolerant of prolonged periods of flooding as long as the water table is below the root crown. Deeper flooding events cause a decrease in growth and an increase in tree mortality (Knighton, 1981).

The *Alnus* and *Salix* cycles may be considered as potential indicators of former wet-dry episodes. The *Alnus* peaks, for example, at 90-100 cm and 55-70 cm depths could represent periods when wetter conditions prevailed, favouring *Alnus* growth; the inter-peak valleys, (i.e., at 70-90 cm) could represent drier intervals with reduced *Alnus* growth. However, *Salix* and *Alnus* are extremely fast growing and short lived, and have only rarely been used in dendrochronology, mainly in inset studies of the 20th century.

Although it was thought that *Alnus* (alder) and *Salix* (willow) cycles might represent wet and dry episodes or other basin-wide cycles recorded by these trees, the cycles do not appear to be correlatable from core to core and thus are not likely to represent basin-wide cycles.

CONCLUSIONS

- A mixture of boreal forest and grassland/parkland taxa dominates the entire record.

- A basal pollen assemblage zone (zone 3) is dominated by *Pinus* (pine); a middle zone (zone 2) is distinguished by upward-decreasing percentages of *Pinus* and upward-increasing percentages of *Picea* (spruce); and an upper zone (zone 1) is characterized by more abundant weed and grass pollen.

- The increase in *Picea* and decrease of *Pinus* at the zone 3/2 boundary, dated at ~ AD 1100, is indicative of a cooler climate and is interpreted as the onset of the Little Ice Age.

- The zone 2/1 boundary is best marked by the first sustained appearance of *Salsola,* dated at ~1895 based on Pb-210. Increases in weed and grass pollen at this boundary are interpreted as the beginning of extensive agricultural development in the region. The Pb-210 date agrees with the likely timing for the arrival of *Salsola* pollen to Lake Winnipeg, about AD 1888 based on documentation of the first appearance of *Salsola* at the headwaters of the Red River.

- The rise in *Salsola* pollen provides a chronological marker that can be correlated amongst cores 3, 4 and 8, occurring at virtually the same depth in each of these cores.

- *Alnus* (alder) and *Salix* (willow) are not correlatable from core to core and thus are not likely to represent basin-wide cycles, and are hence of undetermined origin.

- Preliminary diatom analyses within and between layers of enhanced silt lacked differences, although the high siliciclastic content hindered analysis. Further diatom work of these high siliciclastic-content sediments is not recommended.

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Table 1. List of sample depths for Lake Winnipeg 99-900 core 8

Depth (cm)	
1	60
4	64
8	68
12	76
14	80
16	84
18	88
20	92
22	96
24	100
26	104
28	112
30	120
32	124
34	128
36	136
38	140
42	144
48	152
52	156
56	

Table 2. List of sample depths for palynological analysis of the upper 45 cm of Lake Winnipeg 99-900 cores 3 and 4

Core 3 Depth (cm)	**Core 4** Depth (cm)
21	1
23	9
25	17
27	25
29	27
31	29
33	31
35	33
	37
	39
	45

Table 3. List of sample depths for diatom analysis of Lake Winnipeg 99-900 core 3

Core 3 Depth (cm)	% silt content of sample
9	39.9
10	*47.0
11	*47.8
12	39.4
62	33.4
65	*41.0
66	*40.1
67	*42.0
69	37.7

*layers of greater silt content

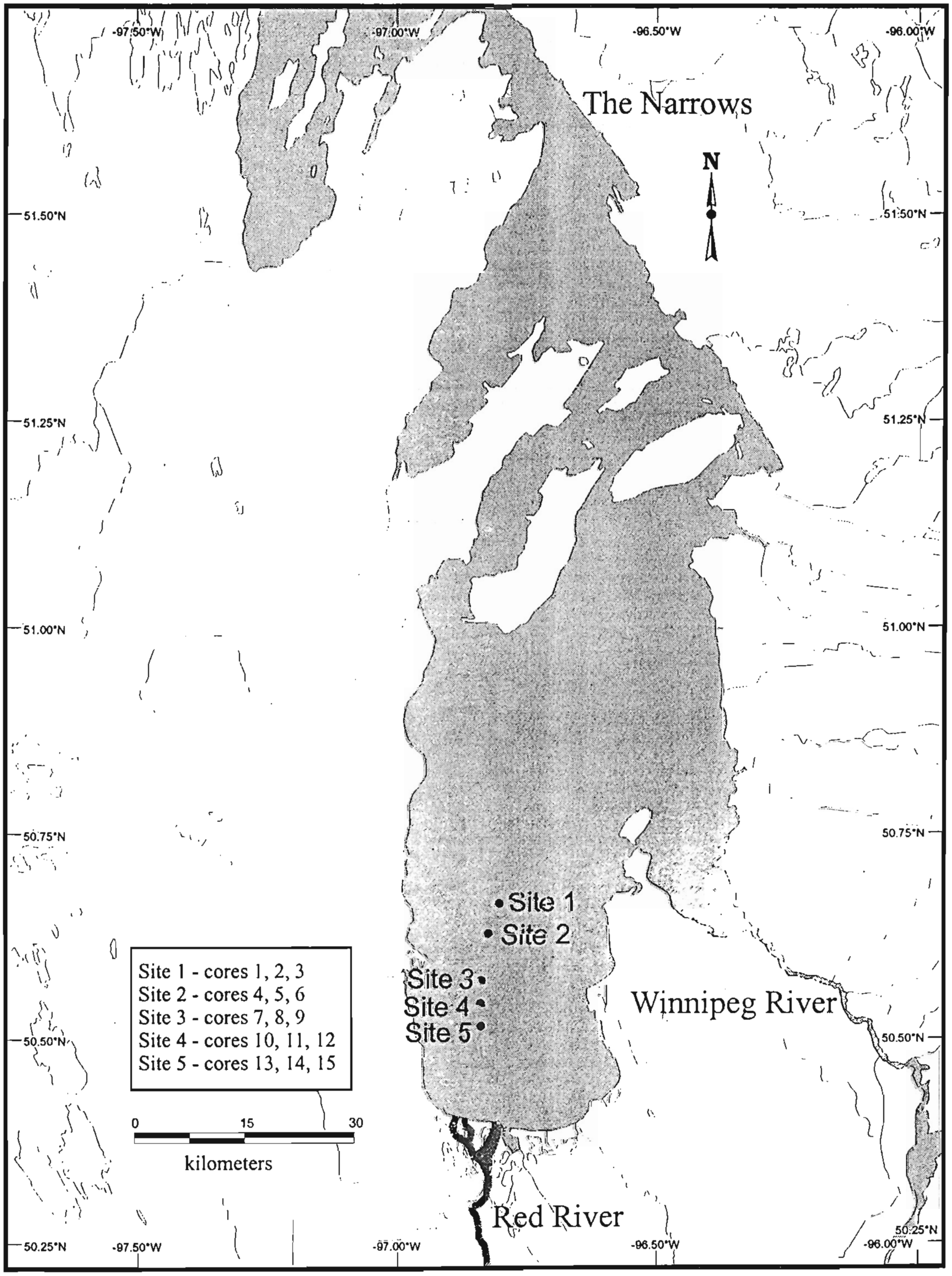


Figure 1. Map of southern Lake Winnipeg showing locations of coring sites

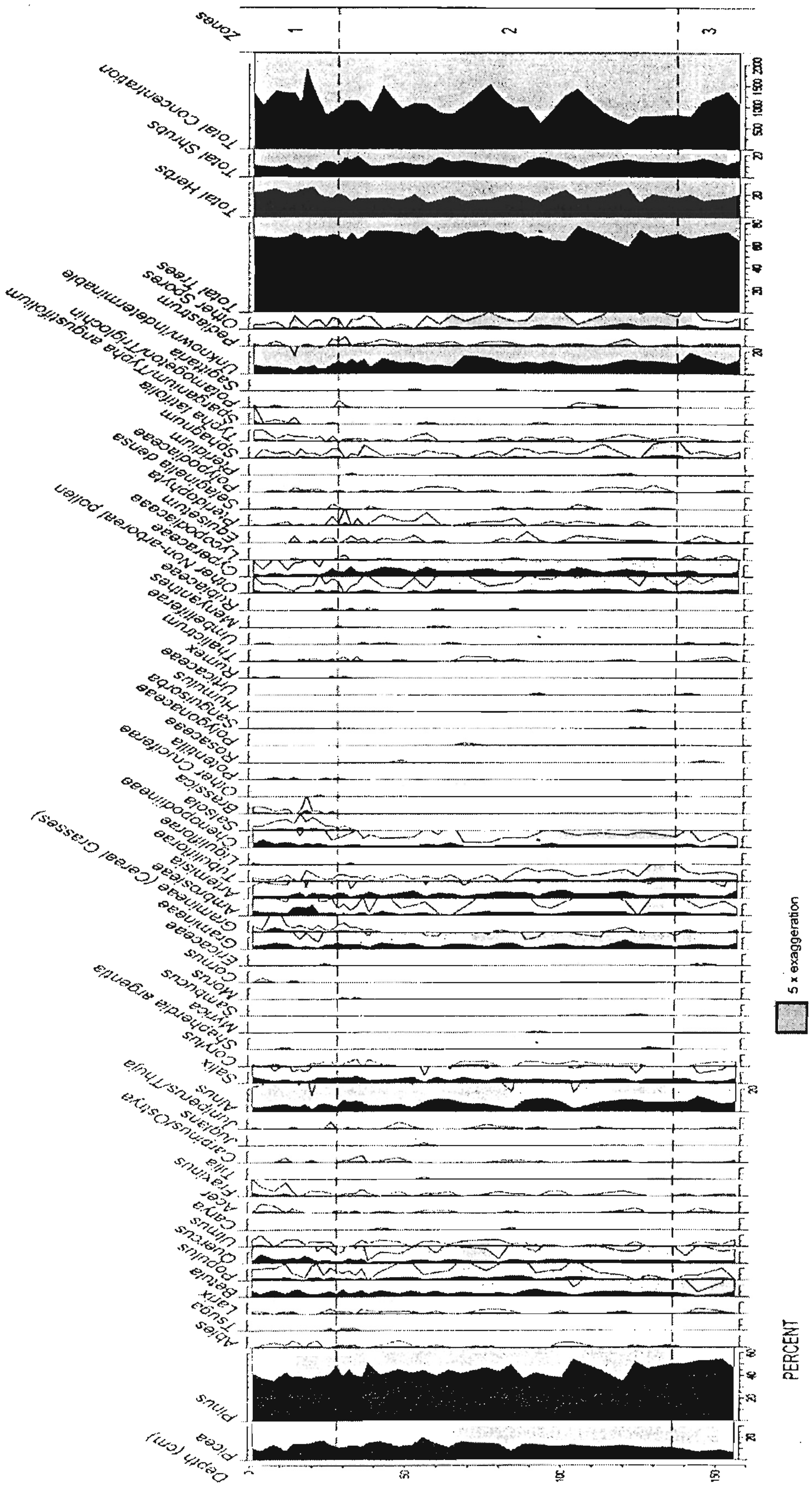


Figure 2. Pollen diagram for Lake Winnipeg 99-900 core 8 showing all taxa. Total pollen concentration is shown as grains/cm^3 x 10^1.

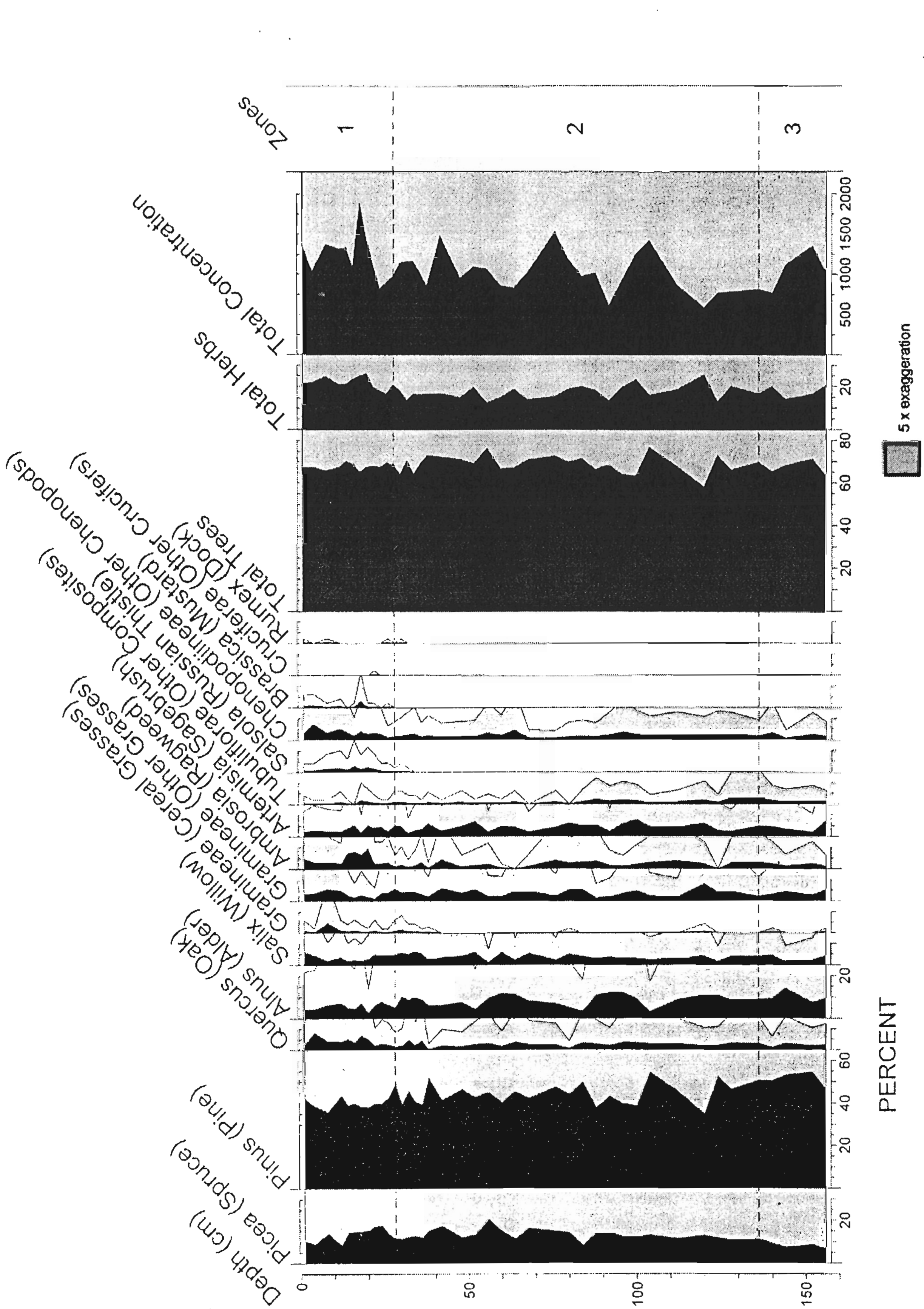


Figure 3. Abbreviated pollen diagram for Lake Winnipeg 99-900 core 8 showing only key taxa. Total pollen concentration is shown as grains/cm^3 x 10^1.

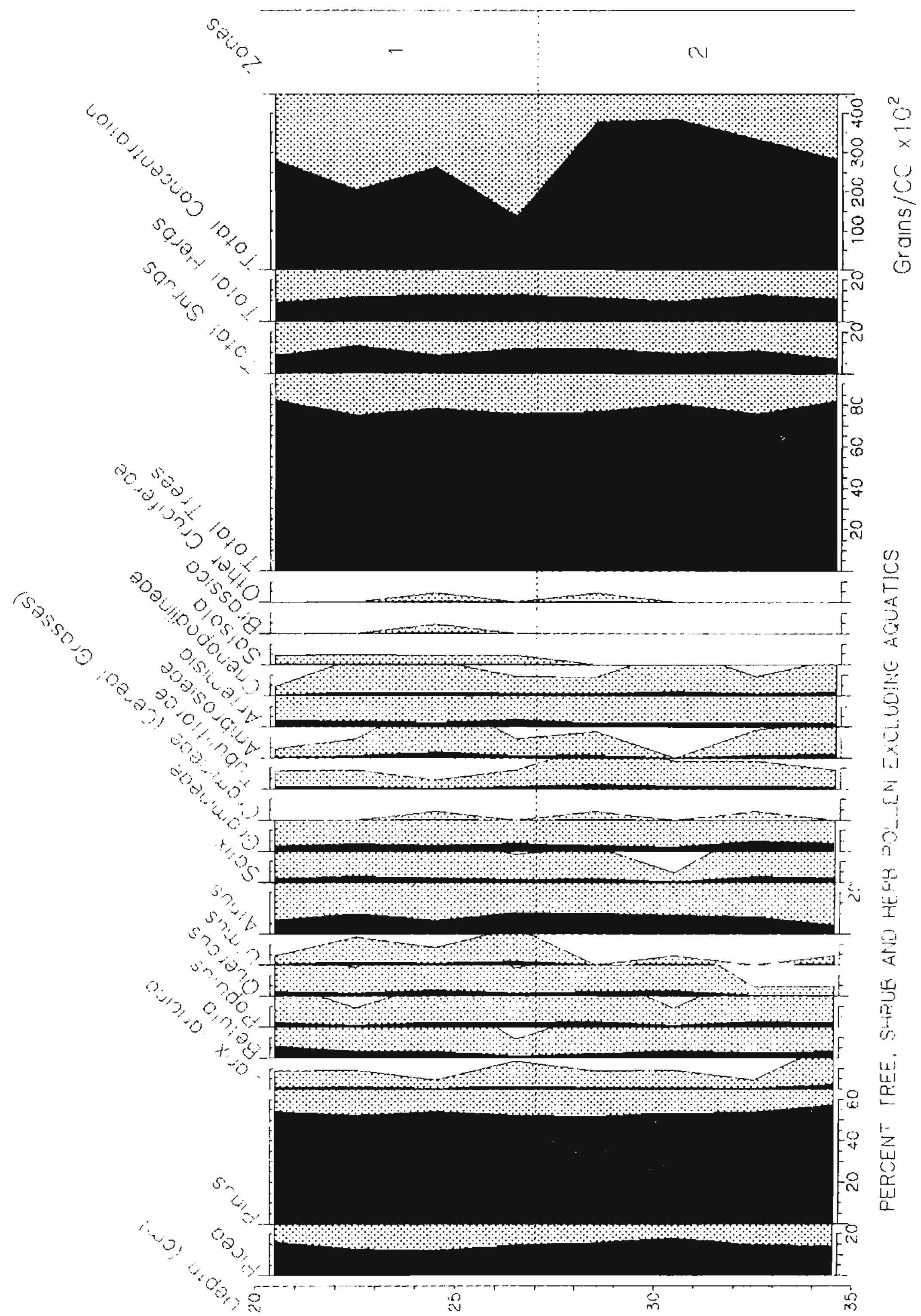


Figure 4. Pollen diagram for Lake Winnipeg 99-900 core 3 (20-35 cm) showing only key taxa. Total pollen concentration is shown as grains/cm^3 x 10^1.

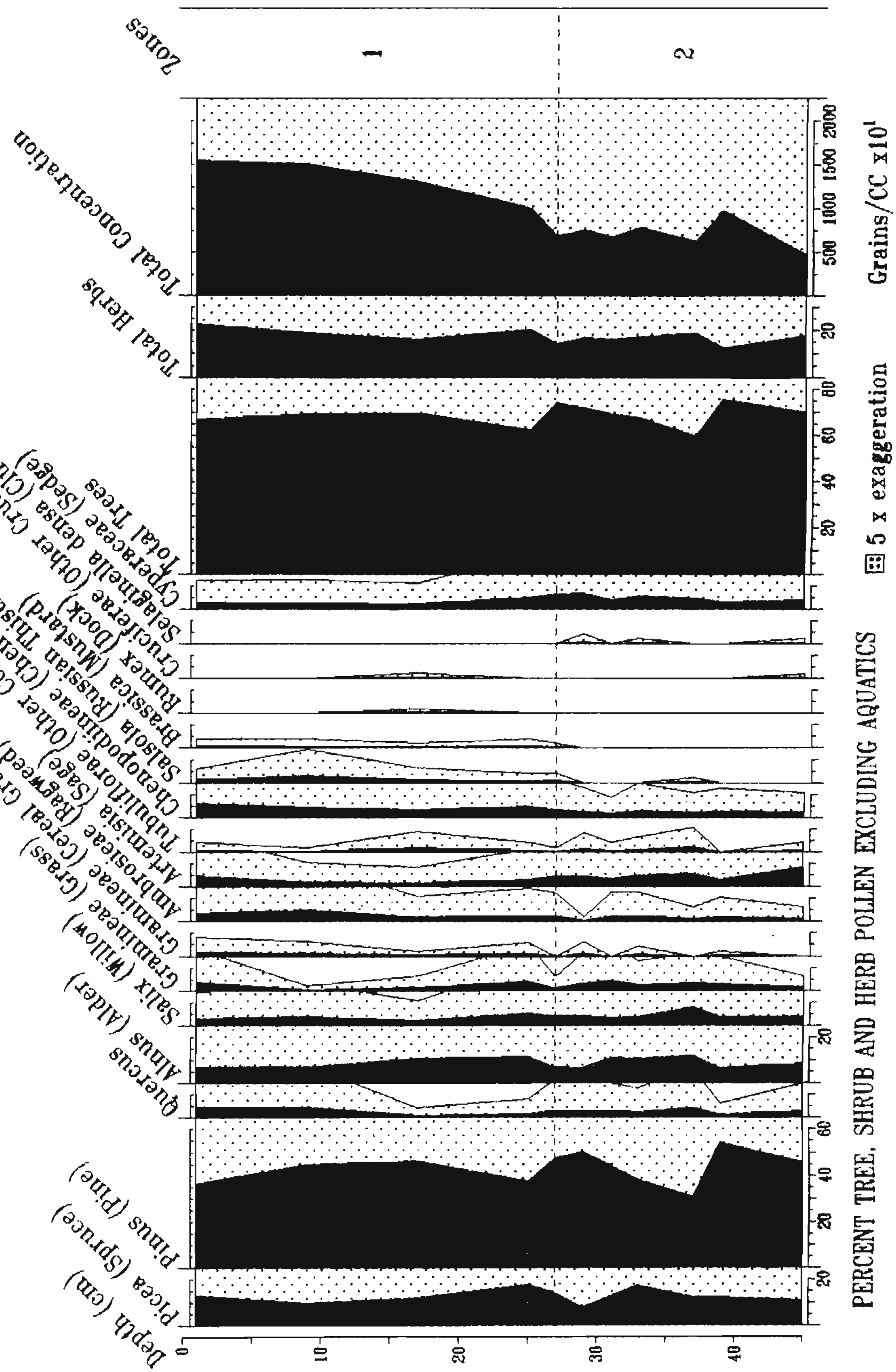


Figure 5. Pollen diagram for Lake Winnipeg 99-900 core 4 (top 45 cm) showing only key taxa

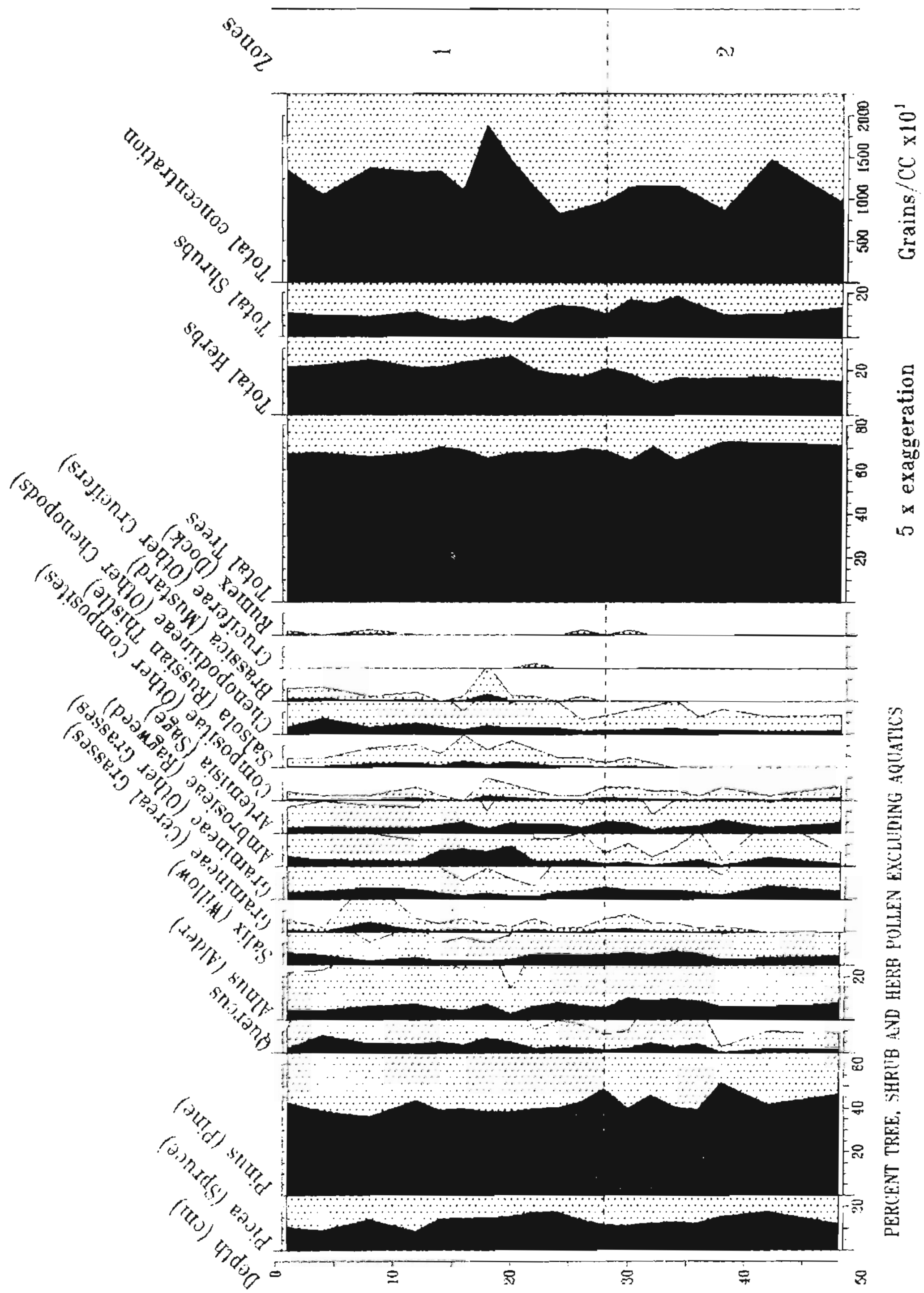


Figure 6. Pollen diagram for Lake Winnipeg 99-900 core 8 (top 50 cm) showing only key taxa. Total pollen concentration is shown as grains/cm^3 x 10^1. Data originally presented in Anderson (this volume).

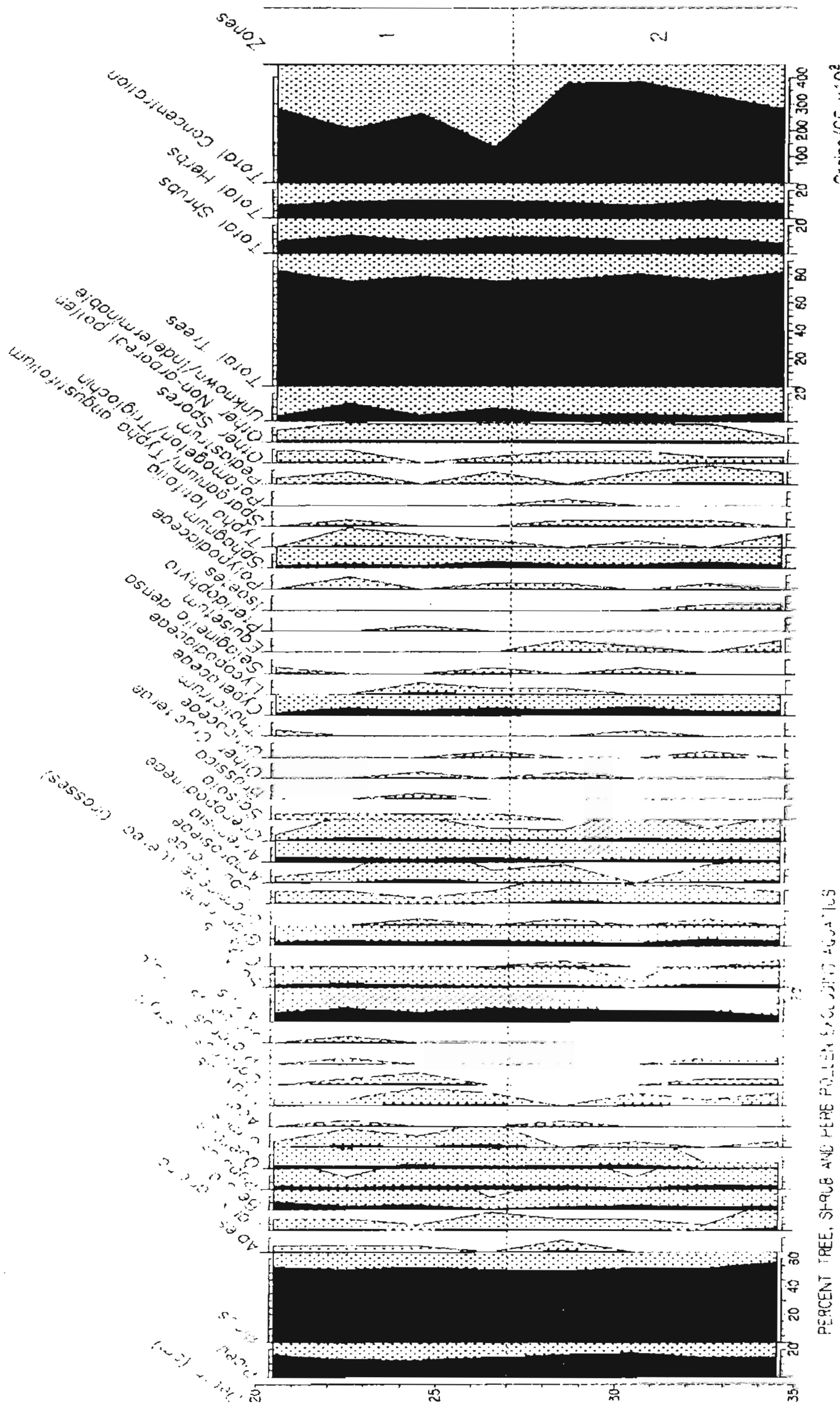


Figure 7. Pollen diagram for Lake Winnipeg 99-900 core 3 (20-35 cm) showing all identified taxa. Total pollen concentration is shown as grains/cm^3 x 10^1.

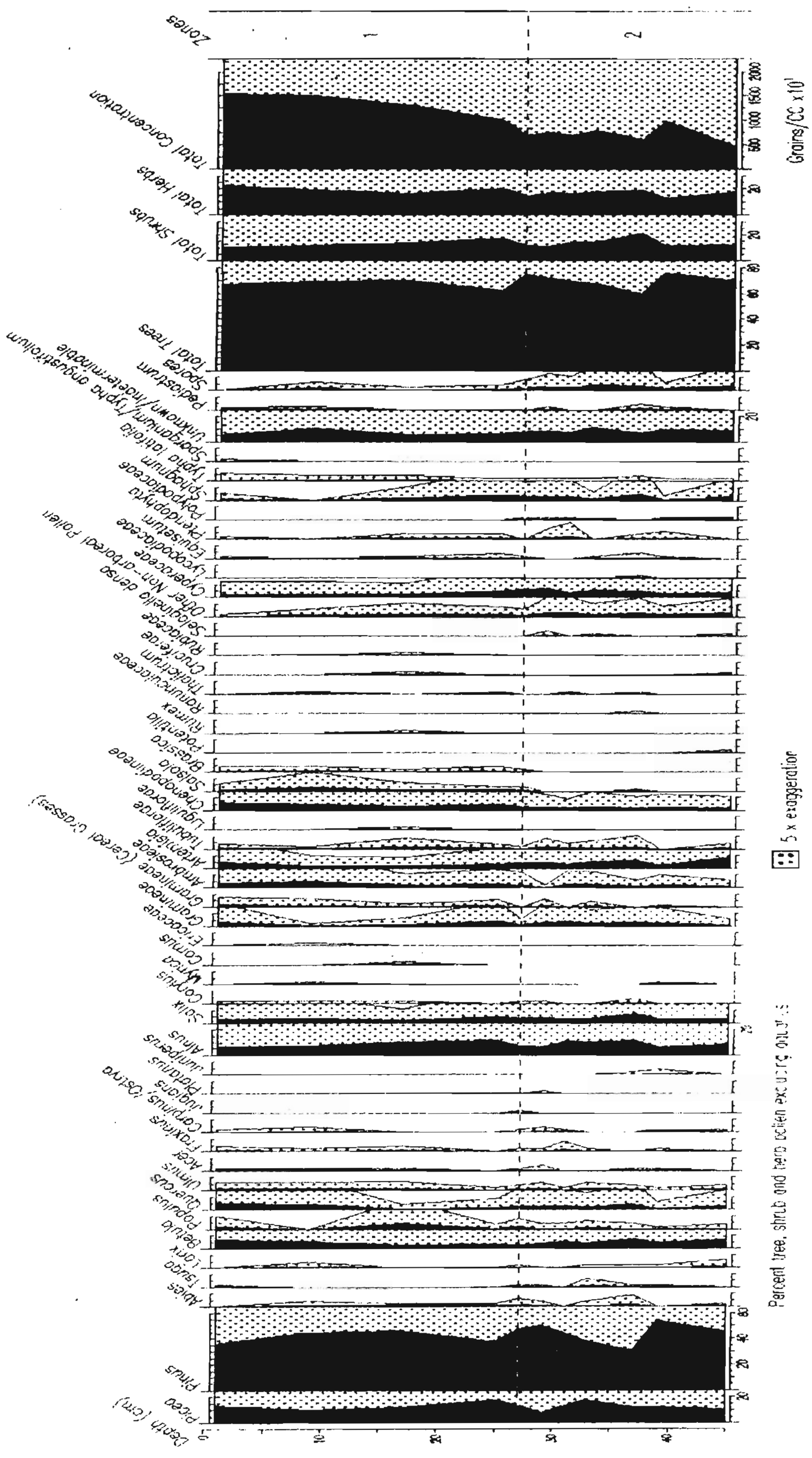


Figure 8. Pollen diagram for Lake Winnipeg 99-900 core 4 (top 45 cm) showing all identified taxa

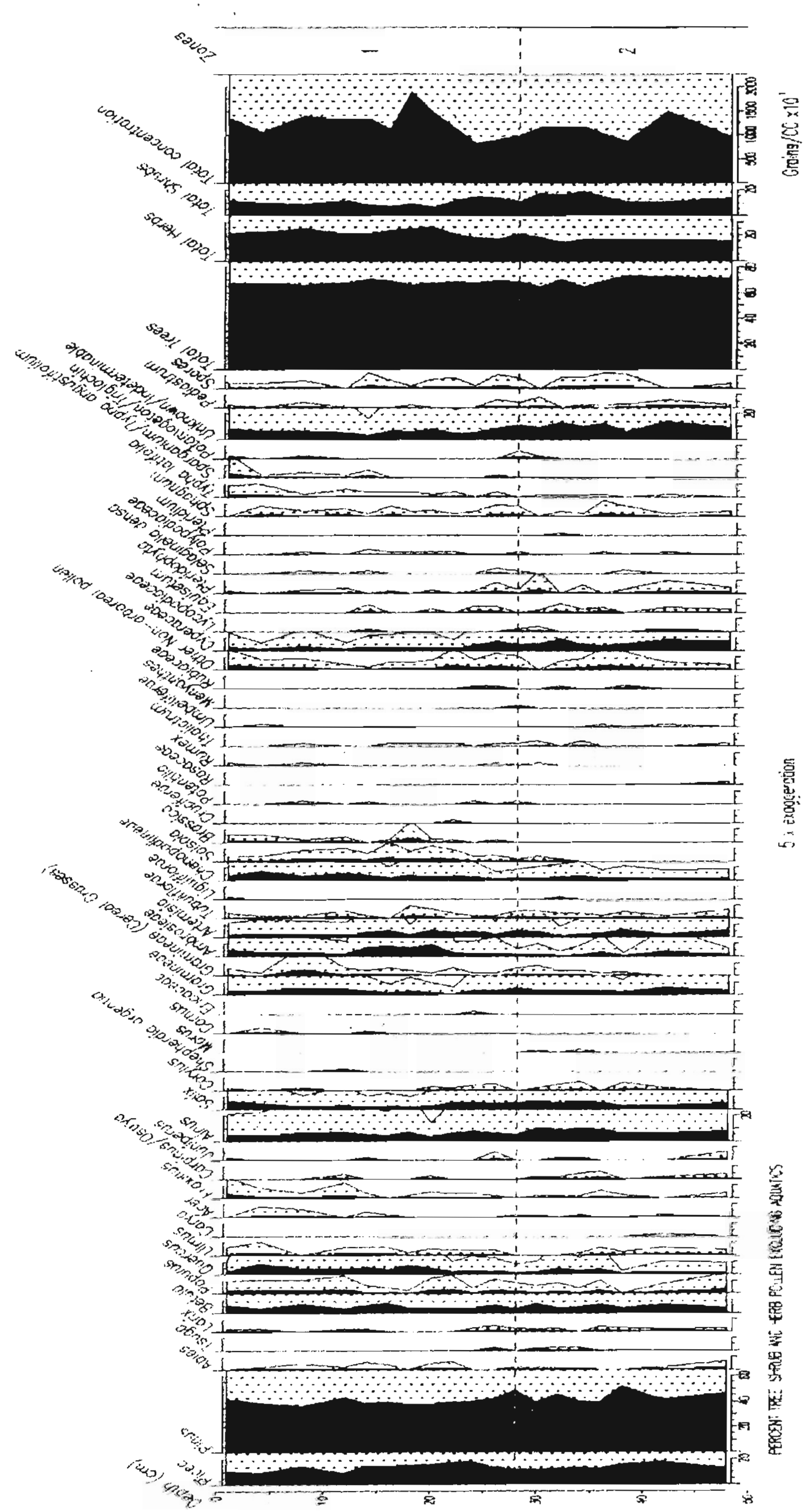
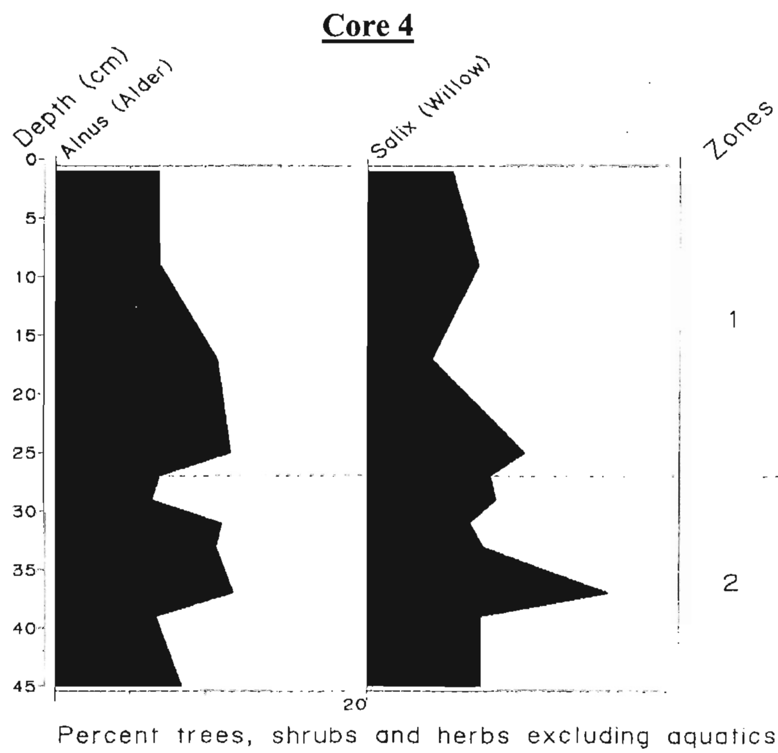


Figure 9. Pollen diagram for Lake Winnipeg 99-900 core 8 (top 50 cm) showing all identified taxa. Total pollen concentration is shown as grains/cm^3 x 10^1. Data originally presented in Anderson (this volume).



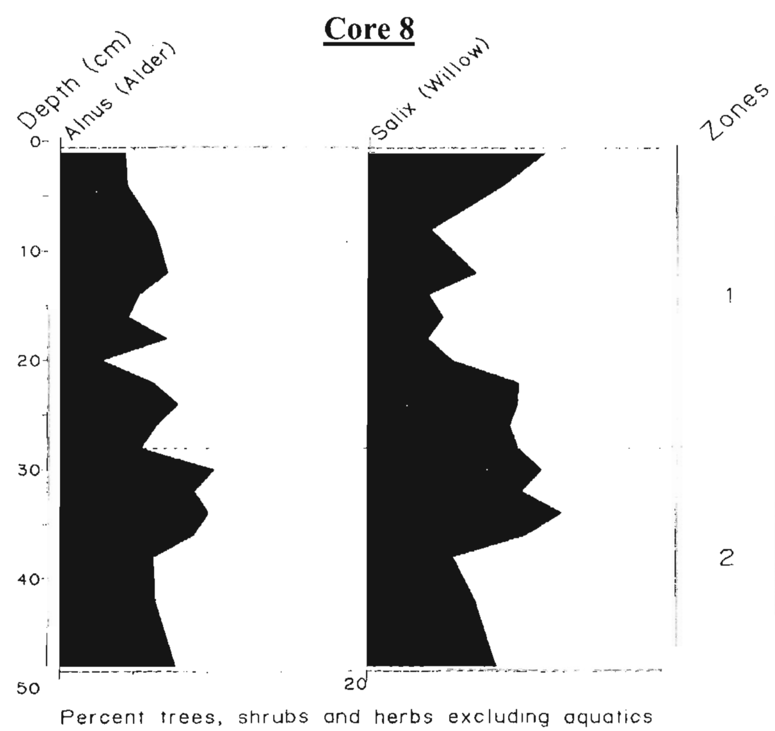


Figure 10. Pollen diagram for Lake Winnipeg 99-900 cores 4 and 8 showing Alnus and Salix profiles for the top 45-50 cm. Total pollen concentration is shown as grains/cm^3 x 10^1. Data for core 8 originally presented in Anderson (this volume).

7. Summary

7. Summary

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This Open File documents the physical, chemical and biological analysis of 15 cores collected from the lake-bottom sediments of southern Lake Winnipeg. Although initially undertaken to search for a Red River flood record, this study has provided information on last millennium sedimentation in the basin and twentieth century change, in addition to recurring events that could be interpreted as floods. The cores, sampled in August 1999 from the CCGS *Namao* (Lewis et al., this volume), were carefully selected to avoid ice scour, and for their proximity to the Red River mouth, the source of the majority of sediments in the south basin.

Paleomagnetic properties (inclination, declination, and intensity) and physical properties (magnetic susceptibility, and density) of the 15 cores were used to select three apparently undisturbed, high-sedimentation-rate cores (King et al., this volume) for detailed chemical, physical, and biological analyses. Six cores were split and consisted of apparently massive to diffusely laminated soft, dark olive grey, noncalcareous silt and clay with black streaks and iron sulphide mottling.

Paleomagnetic inclination marker I1 was identified in 13 of the 15 cores. Dating of an insect sampled at the same depth as the I1 marker in core 9 provided a date of 810 ± 35 yrs BP (CAMS-84850), calibrated to AD 1230 +50/-70 (Telka, this volume, a). The I1 marker has been dated in lakes from Oregon and Minnesota between 870 and 1190 yrs BP. This paleomagnetic marker indicates that the cores represent approximately 1000 years of sedimentation history. Correlation of the I1 marker indicated more rapid sedimentation at the more northerly sites.

Radiochemical dating was completed on cores 4 and 8 using 1-cm sample spacing (Wilkinson and Simpson, this volume). Lead-210 was used to obtain a chronology for the past 150 years. Cesium-137 activity provided confirmation of the accuracy of Pb-210 dates. Peak Cs-137 activity is attributed to mid 1960's peak fallout from atmospheric nuclear bomb testing. A second and later Cs-137 peak of lesser magnitude is dated from Pb-210 results at 1985 and is attributed to contamination, possibly from a documented spill that occurred at the Whiteshell Nuclear Research Establishment at Pinawa in 1979 (Guthrie and Acres, 1980). The occurrence of Cs-137 in the cores below peak levels is likely the result of slight smearing during coring.

The post-1850 chronologies for cores 4 and 8 are well constrained by Pb-210 and Cs-137, and are augmented with a *Salsola* pollen marker (Anderson, this volume). Core 3 was not analyzed radiochemically, hence the *Salsola* marker provides the only age marker for the upper portion of this core. As this marker is present at the virtually the same depth in all three cores, post-1850 ages for core 3 are estimated by averaging depth-equivalent ages from cores 4 and 8. Pre-1850 chronology is determined by linear interpolation between Pb-210 or *Salsola* (core 3) and the paleomagnetic inclination marker I1, although the ages have been adjusted slightly ensure a consistent age for inorganic geochemical markers identified in the cores.

Sedimentation rates shift from an average of 1.3-1.5 mm/yr in the pre-1900 period to an average of 2.6 mm/yr for the post-1900 portion of the cores (Wilkinson and Simpson, this volume). This shift can be attributed to post-depositional compaction, to an increase in sediment derived from enhanced runoff caused by early 20th century landscape changes, or to a combination of the two. The pre-20th century sedimentation rate exceeds the previous sedimentation rate estimate of 1 mm/yr based on the 4000-yr record of south basin Lake Winnipeg sedimentation (Vance and Telka, 1998). This suggests that average sedimentation rates during the last 1000 years may have been slightly greater than the three preceding millennia.

Textural analysis of cores 3, 4 and 8 at 1-cm spacing indicates that the sediments consist entirely of silt and clay, averaging 40 % silt and 60 % clay (Simpson and Thorleifson, this volume, a). Decimeter-scale broad silt maxima and minima, evident throughout the cores, are thought to be the result of shifts in sediment source areas, perhaps brought about by climatic or other factors. Numerous centimeter-scale layers of greater silt content, 6-15 % greater than background, occur about once per century throughout the cores. It is plausible that these layers are caused by Red River floods, as the Red River provides most of the silt to the basin. A steady up-core increase in silt, observable throughout the top 25 cm, is attributed to 20th century changes in land use, particularly the expansion of agriculture and drainage, both promoting runoff.

Geochemical elemental analysis of cores 3, 4 and 8 at 1-cm spacing provides a record of compositional variations

throughout the past millennium (Simpson and Thorleifson, this volume, b). Although many of the 41 elements analyzed show monotonous records, Ca, Mg and Cd show correlatable, decimeter-scale variations throughout the record. Ca and Mg exhibit a strong positive correlation with each other, and some increases correlate with anomalous quantities of silt in the grain-size analysis. Variations in Cd correlate with the abrupt shifts in silt content in core 4, but this correlation is not evident in the other two cores. Increases in the concentrations of Ag, Cd, Cu, Hg, P, Pb, Sb, U and Zn occur in the top 25 cm of the cores, and are in some cases considered to be of sufficient magnitude to be attributed to anthropogenic inputs. However, co-variant increases of metals with total organic carbon imply that some of these increases could be the result of the continual migration of and biological recycling of metals in the upper portion of the lake-bottom sediments (Snowdon and Simpson, this volume). In most cases the concentration of these elements levels off or decreases in the top 10 cm, implying recent reductions in inputs.

Analysis of phosphorus forms, using sequential extraction, indicated that the observed doubling of total P concentrations relative to Al over the last 50 years is largely due to increases in the non-apatite inorganic P fraction (Mayer et al., this volume). This fraction is often associated with anthropogenic sources, suggesting that much of the sedimentary P increase is attributable to changes in the nutrient status of the water column related to anthropogenic inputs. Organic phosphorus exhibits a subtle increase in concentration in the upper 20 cm, likely the result of increases in the primary productivity of the lake, arising from increases in nutrients. Apatite P, which is thought to be of detrital origin, remains fairly constant over the length of the cores, although a slight increase with depth, in longer cores, is attributed to the diagenetic formation of this mineral and/or shift in supply of detrital material. Anomalous spikes in P concentration deeper in the cores, comprised mainly of the non-apatite inorganic P fraction, likely result from natural variations in local oxidizing conditions, possibly induced by changes in water circulation.

Rock-Eval analysis, a means for determining the forms of organic material, of cores 4 and 8 was also completed at 1-cm spacing, primarily to test for influxes of terrestrial organic material during floods (Snowdon and Simpson, this volume). The results, in particular hydrogen and oxygen indices, imply that most of the lacustrine organic matter (OM) was either derived from terrestrial sources, or was significantly altered by diagenesis. Carbon and nitrogen analysis of core 8, however, indicates that the lacustrine OM was primarily derived from aquatic sources (Buhay and Simpson, this volume), but has undergone alteration that has strongly affected Rock-Eval results but not C/N_{org} ratios and $\delta^{13}C_{org}$ values. Overall, the organic carbon and nitrogen contents of the offshore sediments are low, together comprising less than 2 % of the total material. The constancy of the carbon and nitrogen record over the past 1100 years, excluding a shift in the twentieth century, indicates that environmental conditions, such as climate, watershed dynamics and transport mechanisms, have not changed sufficiently during this time to affect these values. However, enrichment of carbon and nitrogen isotopic values at the top of the core suggests that the use of nitrogen fertilizers in the latter half of the 20th century caused increased nitrogen flux to the lake and subsequently enhanced algal productivity, which could be contributing to eutrophication of the lake. Several centimeter-scale layers of depleted $\delta^{13}C_{org}$ content were identified and could have arisen due to nutrient influxes associated with flood events. However, other processes cannot be ruled out for the formation of these layers and further research on another core is recommended.

Macrofossils recovered from cores 5, 7 and 9 for radiocarbon dating were also examined at 5-cm spacing to support paleoenvironmental analysis (Telka, this volume, b). Macrofossils are very sparse in these sediments and the record is dominated by aquatic fauna, suggesting that deep-water conditions have persisted for the past 1100 years. Evidence of floods, in the form of correlatable layers rich in terrestrially-derived material, was not observed. Four-fold increases in macrofossil abundance, and in the insect group Chironomidae, in the top 20-30 cm of the cores implies that nutrient influx began to increase during the period AD 1874 to AD 1934. There is no indication in the form of pre-20th century diminishing fossil identifications or partially-decomposed fossils that the down-core decrease is due to post-burial decomposition.

Palynological analysis measured at a 2- to 8-cm spacing was completed for core 8 and for the tops of cores 4 and 3, to aid dating, correlation, and paleoenvironmental analysis (Anderson, this volume). A mixture of boreal forest and grassland/parkland taxa dominates the entire record. A basal pollen assemblage zone (zone 3) is dominated by *Pinus* (pine); a middle zone (zone 2) is distinguished by upward-decreasing percentages of *Pinus* and upward-increasing percentages of *Picea* (spruce); and an upper zone (zone 1) is characterized by more abundant weed and grass pollen. The increase in *Picea* and decrease of *Pinus* at the zone 3/2 boundary, dated at ~ AD 1100 based on the age model constructed here from radiochemical, radiocarbon and paleomagnetic dates, is indicative of a cooler climate and is interpreted as the onset of the Little Ice Age. The zone 2/1 boundary is best marked by the first sustained appearance of *Salsola,* dated at ~1895 based on Pb-210. This agrees reasonably well with the probable timing for the arrival of *Salsola* pollen to Lake Winnipeg, which would be about AD 1888 based on agricultural records that document the first appearance of *Salsola* at the headwaters of the Red River. The increase in weed and grass pollen at this boundary is interpreted as the beginning of extensive agricultural development of the lower Red River Valley.

Overall, the monotonous records of most of the parameters imply that the south basin has remained a relatively stable environment over the past millennium and that major changes in depositional conditions have not occurred, with the exception of the 20th century. This stability is consistent with past research showing that the north basin of Lake Winnipeg expanded to the south basin about 4000 yrs BP as the lake expanded in response to climate change and post-glacial uplift (Lewis et al., 2000). Changes in water levels caused by post-glacial uplift of the northern end of the lake have apparently been gradual enough not to cause a significant change in the character of the sediments over the past 1000 years. While some parameters exhibit multi-century fluctuations, varying excursions, and 20th century shifts, grain-size results show the clearest signal of recurring events. Several layers of enhanced silt, 1-4 cm thick, with 6-15 % more silt than background are present, in several cases correlating core to core. Given that previous work on sediment budgets indicates that the offshore south basin sediments are predominantly derived from the Red River, a flood origin for these silt excursions is plausible. Future work will explore this possibility. Perhaps most striking in the cores are the 20th century shifts observed in the top 10-20 cm of the cores. Sedimentation rates and to some extent grain size have been increasing since the late 1800's, presumably due to the expansion of agriculture and drainage. Associated increases in Ag, Cd, Cu, Hg, Pb, Sb, U and Zn concentrations since the early 1940's are attributed in some cases to contamination from a variety of local and airborne anthropogenic sources. Concentration plateaus and decreases in the top 10 cm of the cores for several elements imply recent reductions in inputs. A significant influx of Cs-137 seems to have occurred in the mid 1980's, perhaps attributable to a spill that occurred at the Whiteshell Nuclear Research Establishment at Pinawa in 1979. Parallel increases in the number of macrofossils, $\delta^{13}C$ and $\delta^{15}N$, and non-apatite inorganic phosphorus imply enhanced nutrient influx and lake productivity beginning in the late 1800's and peaking in the past 40 years.

This Open File provides a characterization of the physical, chemical and biological properties of the lake bottom sediments of southern Lake Winnipeg, yielding a record of sedimentation over the last millennium. The sediments document a history of change over the past century and will provide a record against which future environmental change can be gauged.

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8. Netley Marsh project

8.1 Reconnaissance of Netley Marsh stratigraphy: assessment of the potential for a Red River flood-related stratigraphic record

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ABSTRACT

Following the 1997 Red River flood, research addressing the history and controls on the flood hazard has included an assessment of whether a record of flood history and drainage basin evolution might be obtained from Netley Marsh, the back-barrier lagoon complex at the south end of Lake Winnipeg. It was hoped that a better understanding of the controls on sediment input, including the impact of flood events, would be gained, and that the need for further analysis would be determined. Six cores were collected from the east central portion of Netley Lake, the largest water body in Netley Marsh. One of the cores was analyzed with respect to age, grain size, and macrofossil abundance and diversity. Three radiocarbon dated *Scirpus* seeds indicate that the 1-m long core likely represents approximately 400-500 years of sedimentation. An abrupt up-core increase in silt at a depth of 84 cm, accompanied by abrupt decreases in sand and clay, indicates a major change in sedimentation. Abrupt decreases in Tubellaria, Spongillidae, *Scirpus* and Chironomidae between 70 and 85 cm depth indicate a shift to more stressful environmental conditions, while the proliferation of *Daphnia*, which thrives in times of stress, above this depth indicates these conditions dominated for some time. The abrupt shifts in grain size and macrofossils could have resulted from an abrupt water level change or enhanced sediment influx, perhaps brought about by construction of a temporary cut in 1913-14 that opened a conduit between the Red River and Netley Lake, from the ~1970 breaching of the levee along the dry bed of the former cut, or from some other event. Further research is recommended to verify the cause as uncertainties in the sporadic history of levee breaches, the character of the incoming sediments and the chronology prevent an adequate understanding of how floods might be manifested in Netley Lake sediments. Given that material categorized as sand corresponds with increases in coarse organics, it seems that the sand fraction may be predominantly organic rather than clastic. In order to assess whether shifts in grain size are attributable to clastics, perhaps brought in by floods, or to organics, the samples would need to be analyzed for total organic carbon (TOC). For future study, it is recommended that coring sites be distributed throughout Netley Lake to provide information on spatially variable processes, such as the influx of riverine sediment close to the breach or the influx of material from the northern barrier island complex in the north portion of Netley Lake. Other recommendations include analysis of multiple proximal cores for corroboration of trends, dating of cores using Pb-210 and strategically placed radiocarbon dates, sampling and analysis to better characterize inputs to the lake, and additional analyses, particularly the determination of total organic carbon (TOC).

INTRODUCTION

The 1997 Red River flood was a major natural disaster that forced the evacuation of 28,000 residents in Canada (Manitoba Water Commission, 1998) and 75,000 residents in the United States (Todhunter, 2001). Damages are estimated at 325 million US dollars in Manitoba (Manitoba Water Commission, 1998) and 4.5 billion US dollars in North Dakota and Minnesota (International Red River Basin Task Force, 2000). Red River floods are triggered by abrupt spring snowmelt and flows that exceed the capacity of the Red River channel, resulting in extensive inundation of the surrounding flat prairie landscape (Brooks and Nielsen, 2000). Much is being done to reduce comparable damage and disruption in the future through enhanced dikes and diversions, as well as revised land use and water management practices. Planning of enhanced flood protection measures requires an optimal understanding of the risk, including a better understanding of the range of flood magnitudes, major flood frequency, and whether natural factors are changing the flood risk. Research therefore has addressed the nature of the largest known flood, in 1826, whether comparable large floods have occurred in recent centuries, and how geomorphic, climatic, land use, and tectonic factors may be changing the flood hazard (Brooks et al., 2003).

The mitigation of Red River floods has been addressed from a structural approach that includes the Red River Floodway that diverts Red River flow around Winnipeg, the Portage Diversion that diverts Assiniboine River (Figure 1) flow to Lake Manitoba, the Shellmouth Dam that retains water in an upper Assiniboine reservoir, and many kilometers of primary dyking that confine Red River flow through Winnipeg (Mudry et al., 1981). This flood protection infrastructure has been very effective since the opening of the Floodway in 1968, and billions of dollars in flood damages have been avoided, particularly during the 1997 flood (Mudry et al., 1981; International Red River

Basin Task Force, 2000). During this flood, the Floodway was utilized to slightly above design capacity (Rannie, 1998), and only a minor change in weather conditions could have resulted in a catastrophic dyke failure causing large-scale flooding in Winnipeg (International Red River Basin Task Force, 2000). To reduce the risk of a multi-billion dollar flood disaster, recent studies have proposed enhancing the flood protection infrastructure at Winnipeg, specifically by expanding the Floodway or constructing a detention dam near St. Agathe (International Red River Basin Task Force, 2000; KGS Group, 2001). The understanding of flood recurrence and changes in flood hazard is being enhanced through a geoscientific research program that provides a long-term perspective on flood history and processes influencing flooding.

STUDY AIM

Coring in the Netley Lake back-barrier lagoon complex at the south end of Lake Winnipeg, through which the Red River flows to its mouth, was undertaken to obtain a better understanding of the controls on sediment input. The objective was to identify flood events that might be recognizable in the bottom sediment stratigraphy, due to changes in physical and biological properties of the sediments. Six cores were collected in Netley Lake in 2001 and one core was dated using ^{14}C and analyzed for grain-size and macrofossil content. The purpose of analyzing a single core was to provide a preliminary assessment of changes in the lake sediments and processes affecting the lake, and to determine the need for further analysis of existing cores or collection of additional cores. On the basis of this data, an assessment was made of the potential of Netley Lake cores to document Red River flooding. This included an assessment of whether sufficient information was gathered to reach conclusions on flood history and environmental processes in the Red River watershed. As this study is the first detailed study of Netley Lake and will form the basis for future study, recommendations related to coring, chronology, and analyses, are presented.

GEOGRAPHIC SETTING

Netley Lake is located in western Netley Marsh (Figure 1), a system of interconnected shallow lakes, ponds and channels that constitute the marshy region behind the barrier island complex at the southern end of Lake Winnipeg. Approximately 4 km south of Lake Winnipeg, the Red River branches into three smaller channels, including the West, Main and East Channels. Salamonia Channel branches off of the West Channel about 2.5 km south of Lake Winnipeg. Levees, breached in places by crevasse splays, separate the channels from the surrounding marshes and lakes (Nielsen and Conley, 1994). Netley Lake is the largest of the lakes in the marsh and is approximately 5 km^2. Water depths observed during fieldwork were approximately one meter. The major influx of water to the lake is from the Red River through an intermittent, narrow (~500 m wide) opening along the southeast side of the lake, and from Lake Winnipeg through openings at the north end of Netley Lake through which flood and ebb flows respond to wind-driven changes in the level of Lake Winnipeg. The Red River, prior to entering Netley Marsh en route to Lake Winnipeg, flows 880 km from its origin at the confluence of the Bois de Sioux and Otter Tail rivers in southern North Dakota and Minnesota. It drains an area of 290 000 km^2, including the 153 000 km^2 from the Assiniboine River watershed. The Assiniboine River joins the Red River at the city of Winnipeg, approximately 100 km south of Netley Marsh. The Assiniboine River watershed encompasses portions of southwest Manitoba, northwest North Dakota, and southeast Saskatchewan.

PREVIOUS INVESTIGATIONS

Surficial Geology

The Red River Valley formed by erosion of Mesozoic shale down to Paleozoic carbonate during the Tertiary and Quaternary Periods, which created a lowland between the Manitoba Escarpment to the west and the Precambrian shield to the east. During the last retreat of glaciers at the end of the Wisconsin glaciation, glacial Lake Agassiz encompassed the region (Upham, 1895; Teller and Clayton, 1983). During the 3000 years that the lake existed, a thick layer of low-permeability glaciolacustrine clay was deposited, forming the flat clay plain of the Red River Valley, a surface that slopes gently towards Lake Winnipeg. The Red River developed across the bed of the waning glacial Lake Agassiz between 8.2 and 7.8 ka BP (Fenton et al., 1983; Teller et al., 1996). The modern river valley is up to 15 m deep and 2.5 km wide.

The south shore of Lake Winnipeg and the deposits of Netley Marsh consist entirely of late Holocene sediments, with the exception of bedrock outcroppings at Stoney Point (Nielsen and Conley, 1994). The south basin of Lake Winnipeg is separated from Netley Marsh by beach sediments that form a fringing barrier shoreline (Nielsen and Conley, 1994; Forbes and Frobel, 1996). Southward migration of the barrier is occurring by wash over and breaching of small lakes within Netley Marsh. The principal long-term cause is isostatic uplift of the north end of Lake Winnipeg at a rate higher than in the south (Nielsen, 1996). Sustained water-level rise at a rate of about 20 cm/century (Lewis et al., 2001) has caused the southward migration of the barrier shoreline. Nielsen and Conley (1994) examined aerial photographs and maps from the past 50-100 years and concluded that both long-term changes due to differential uplift of the outlet and short-term changes due to storms, wind set-up, regional flooding and lake-level trends, and climate fluctuations have occurred. During the drought of the 1930's, the south shore of Lake Winnipeg shifted northward, waters in Netley Lake were low, and hay fields, farms and roads were established in many parts of Netley Marsh. In the 1940's when precipitation increased, water levels in Lake Winnipeg and

Netley Marsh rose, and the agricultural activity was displaced. The higher water levels have persisted since the 1940's.

The Barrier Island Complex

The barrier island complex that separates the south basin of Lake Winnipeg from Netley Marsh may serve as a source of sediment to Netley Lake. During periods of high water levels on Lake Winnipeg coincident with winds from the north, sediment is eroded from the foreshore and transported into the marshes through inlets or overwash, resulting in overwash fans and flood deltas (Nielsen and Conley, 1994). Radiocarbon dating of drowned stumps indicates 60 to 100 m of shoreline recession since AD 1650 (Nielsen, 2000), although surveys of the 20th century imply rates up to 5m/year (Penner and Swedlo, 1974). The upper foreshore portion of the barrier island complex consists of unconsolidated very coarse sand with minor gravel (Nielsen and Conley, 1994). Clay and silt occur in places in the lower foreshore, and are interpreted as relict marsh sediments. Deposits of eroded till, containing large boulders, comprise the foreshore in a number of places. Sediments in the backshore and dunes are similar to those of the upper foreshore. Driftwood lines, flotsam and welded bars on the backshore indicate that subaqueous processes are responsible for most of the sediment transport to this part of the barrier island (Nielsen and Conley, 1994).

Netley Lake Stratigraphy and Chronology

Knowledge of the stratigraphy of Netley Lake sediments is limited to descriptions accompanying two radiocarbon dates obtained in 1996 from auger samples (Morlan et al., 2000) (Figure 2). Netley Lake sediments are thought to directly overlie Lake Agassiz clay, based on trends inland and offshore (Todd et al., 1998). The first auger sample, collected by E. Nielsen from the southern margin of Netley Lake (50.304°N, 96.876°W), was described as organic silt, occurring at 0 to 114 cm depth, directly overlying Lake Agassiz clay (Morlan et al., 2000). The second sample, collected by E. Nielsen from the central portion of Netley Lake (50.316°N, 96.860°W), consisted of firm, brown organic-rich clay, occurring at 0 to 190 cm depth, overlying Lake Agassiz clay. Ages for the bases of these organic rich sequences were determined by radiocarbon dating of a *Scirpus* seed from the base of each sequence. The southward transgression and onset of sedimentation for Netley Lake can be established from the two sites at ~650 BP (650 ± 60 BP, CAMS-27256) and 450 BP (450 ± 70 BP, CAMS-27255) for the central and southern sample sites, respectively (Morlan et al., 2000).

The Red River

The Red River is a mud-dominated, single-channel meandering stream with a sinuosity of 1.1 to 3.0 and an average valley gradient of 0.0001 (Brooks, submitted, a). The shallow depth of the valley and its low gradient limit the capacity of the valley to contain extreme flows, hence when floodwaters overtop the valley, large areas are inundated. Reflecting the fine grained suspended load typical of the river, the alluvium along the channel is mostly silt, with minor sand beds and ranges in total thickness from ~ 15 to 22 m (Brooks, submitted, a). The texture and bedding style of the alluvium consist of massive silt beds, deformed and disrupted silt beds, minor sand and silt beds, and local deposits of sand and pea gravel. The alluvium sequence consists oblique accretion and/or channel deposits, oblique accretion deposits, and overbank deposits. Large-scale mass movements along the convex banks are considered the cause of deformed beds. The banks along both straight and curved channel reaches experience mass movements in the form of very slow slides or slumps. Fluvial erosion is actively occurring along the toe of such banks. Net sedimentation along many river meanders is occurring along the downstream extension of the concave bank well beyond the meander apex rather than at a point bar deposit situated at the apex itself (Brooks, submitted, a). Fine-grained sediments have been observed as breccias transported by traction, but the lack of sand-sized aggregates in the alluvium is attributed to post-depositional coalescence by compaction (Brooks, submitted, a). Overall, the Red River is a low-energy, silt-dominated alluvial system that is poorly documented in the fluvial geomorphology and sedimentology literature.

At Emerson, Manitoba, about 100 km south of Winnipeg, the mean annual discharge of the Red River is 98 m^3/s and the lowest and highest mean monthly flows are 22 m^3/s (February) and 362 m^3/s (April), respectively (Water Survey of Canada data, 1912-1995). Discharge and suspended sediment records for the 8-year period between 1978 and 1986 were examined and assessed by Glavic et al. (1988). Peak flow generally occurs in April or May following spring snowmelt, secondary peaks can occur in June and July, and smaller peaks can occur in the August-October period. The summer peaks are caused by high rainfall. The suspended sediment load of the river is over 90 % silt and clay, regardless of sediment concentration or river discharge (Glavic et al., 1988). Suspended sediment concentrations generally begin to rise around the time of the spring snowmelt, attaining concentrations of 400 mg/L to 800 mg/L. Peak suspended sediment concentrations, ranging from 300-1900 mg/L, are usually attained in the May-August period, often occurring simultaneously with increases in rainfall runoff. However, several concentration peaks occur without a concurrent increase in flow. The annual suspended sediment load at Emerson varies between 0.4 and 1.5 million tonnes, 51 % of which is transported over a 37 day period beginning in March or April and 35 % of which is transported during the June-September period (Glavic et al., 1988). The mean annual suspended load for the period 1956-1985 at Emerson, St. Agathe, and Lockport was 865,750 tonnes (gross drainage area=104,000 km^2, mean daily concentration=223 mg/L), 1,291,330 tonnes (gross drainage area=117,000 km^2, mean daily concentration=263 mg/L), and 1,891,140 tonnes (gross drainage area=287,000 km^2, mean daily concentration=263 mg/L), respectively (Penner et al., 1986). The mean annual suspended load on the Red River floodway at Lockport was 371,7500 tonnes (mean daily concentration=483 mg/L) (Penner et al., 1986). Little study has been done on the bed load of the Red River, although Glavic et al. (1988) indicated that the bed load of the Red River at Emerson is 57-81 % silt and clay, averaging 72 %, while sand and gravel comprise 10-43 % and 0-17 %, respectively. Although records of peak discharge for the Red River are available for the past century, information on the sediment load during floods is not available.

The Assiniboine River

Flow to the Red River from the Assiniboine River is significant, being derived dominantly from snowmelt and early spring rainfall. The Assiniboine River contributes about 25 % of the total floodwaters of the Red River, most of it derived from the small, northern part of the drainage basin formed by the southern slopes of the Riding, Duck, and Nut Mountains (Red River Basin Investigation, 1953). There are no exceptionally high floods on record for the Assiniboine River between 1900 and 1953, the largest floods occurring in 1916 (615 m^3/s at Headingley), 1922 (500 m^3/s at Millwood), and 1923 (650 m^3/s at Brandon, 625 m^3/s at Portage). Records vaguely indicate an extreme flood in 1882 (Red River Basin Investigation, 1953). About 60-80 % of the average annual streamflow occurs in the April-June period. Sediment transport also is dominated by the freshet and spring runoff period, when over 80 % of the total annual sediment discharge occurs. The mean annual load on the Assiniboine River at Headingley, just west of Winnipeg, was 434,720 tonnes (gross drainage area=153,000 km^2, mean daily concentration=243 mg/L) for 1956-1985 (Penner et al., 1986). In contrast to the erosive nature of the Red River, the Assiniboine River is an actively aggrading, meandering river in its lowest reach, with a mean meander wavelength of 1495 m and a mean channel width of 107 m. There has been little research into the nature of Assiniboine River deposits. The Assiniboine River presumably carries a coarser load than the Red River, acquired from erosion of sandy glaciofluvial sediments along its course, although the proportions of clay, silt and sand in the suspended load have not been determined.

Fluvial Levees

Geomorphic study of the river margin deposits of the Red River in Manitoba has thus far been limited to the region upstream from Winnipeg. This region of the river is confined by banks whose formation is controlled by overbank flows, oblique accretion, and large-scale mass movement (Brooks, submitted, a; b). Overbank deposits in the vicinity of Netley Marsh appear to be quite different in nature, and can be classified as levees, crevasse channels and crevasse splays, using the terminology of Miall (1996). A fluvial levee is defined as the elevated portion occurring between channels and floodplains (Brierley et al., 1997), best developed on the concave bank of bends (Allen, 1965). As the levee deposits in Netley Marsh have not been documented, examples of modern levees are reviewed here. The lithofacies and architecture of levee and crevasse deposits in modern fluvial environments have been described by Coleman (1969) for the Brahmaputra River, D.G. Smith (1986) for the Magdalena River, Farrell (1987) for the Mississippi River, N.D. Smith et al. (1989) for the Cumberland Marshes, Saskatchewan, and Brierley (1991) for the Squamish River. Levees, which are generally decimeters to meters high and meters to kilometers wide, typically consist of rhythmically bedded units of silty, ripple-laminated sand (Miall, 1996). Levees reach their maximum thickness proximal to the river channel, thinning and fining away from the channel margin. Laminations representing flood events may be present, although laminations are commonly obscured by bioturbation and root development. Observations made by the authors in the field indicate that the levees near Netley Lake rise about a meter above the surrounding water level.

Crevasse-splay deposits develop as water containing both coarse bedload sediment and suspended sediment expands and loses velocity suddenly having escaped the main channel through a breach in the levee. Delta-like deposits result adjacent to the margins of main channels, which may be indistinguishable from lacustrine delta deposits. Crevasse-splay deposits are typically lens shaped, up to 10 km long, 5 km wide, and typically 2-6 m thick (Miall, 1996). They are generally comprised of medium-grained sandstone with such features as plant roots, bioturbation, trough cross-bedding, and ripple lamination. Grain size decreases away from the main channel. Well developed crevasse splays, typified by the lower Mississippi River deposits, exhibit three stages. The first is of incipient crevassing and progradation, which may be manifested as interlaminated sand (open splay) and silt (closed splay), exhibiting an upward-coarsening trend. The second is of a fully developed splay, which generally exhibits a coarser-grained texture. The third is of upward fining if abandonment of the splay takes place.

Crevasse channels form the link between levees and crevasse-splays. In most cases, the channel forms naturally, following a breach of the channel margin, which introduces water and sediment to the backswamp environment. Crevasse channels range from a few tens of meters to a few hundred meters in width, and from less than a meter to 5 meters in depth, depending on the scale of the river (Miall, 1996). These channels incise levee and backswamp deposits and typically form a scaled-down, delta-like distributary system. The deposits of these channels are fine- to medium-grained sand with trough cross-bedding and ripple cross-lamination (Miall, 1996). Much of these deposits are finer grained than the deposits of the main channel, although the coarsest fraction is often similar to that of the deposits of the main channel (Miall, 1996).

Flood-Related Geoscience Research

Previously, the timing and magnitude of Red River floods was known only from instrumental flood stage and historical records. Instrumental flood stage records for the Red River Valley began in 1875, and since this time floods equal to or exceeding 2500 m^3/s have occurred on six occasions and those equal to or exceeding 3000 m^3/s have occurred three times (Figure 3). Archival records used to develop a flood stage record for the 19th century indicate that six floods exceeding 2500 m^3/s occurred between 1800 and 1875, five of which equal or exceed 3000 m^3/s (Figure 3) (Rannie, 1998).

The record of Red River floods prior to gauging of the river is being enhanced through the study of tree rings (St. George and Nielsen, 2000; *in press*), floodplain lake cores (Medioli, 2001; 2003), floodplain deposits (Brooks, submitted, c; Lian and Brooks, *in preparation*), archaeological sites (Kroker, 1997; 1998), and Lake Winnipeg cores presented in this Open File.

Tree-ring studies (St. George and Nielsen, *in press*) have provided evidence for floods on the Red River predating the archival record. The reliability of this method has been confirmed by the identification of five of the seven largest floods in the Lower Red River (LRR) basin during the last 200 years (1826, 1852, 1950, 1979, and 1997). Floods in 1861 and 1996 were not recorded by the tree rings. Prolonged inundation from high magnitude Red River floods, such as the 1950 flood or larger, appears to cause bur oak trees (*Quercus macrocarpa* Michx.) growing along the river to develop anatomically distinctive tree-rings, or 'flood rings', that can be used to identify Red River floods (St. George and Nielsen, 2000). Additional LRR basin floods in 1747 and 1762, which predate the archival record, were indicated by tree rings. Flood identified for the Upper Red River basin may not be applicable to the LRR basin. Relative flood magnitudes were inferred on the basis of frequency of associated flood rings at a number of sites, as larger floods inundate more trees. The flood of 1826 was deemed the most severe flood to occur in the last 352 years. The magnitude of a flood identified at 1747 was interpreted to be equivalent to that of the flood of 1852. Magnitudes of floods in 1762 and 1950 were inferred to be equivalent, as were floods in 1979 and 1997, from the tree-ring perspective. Tree-ring correlation of flood magnitude for 1979 and 1997 indicates that there may be a mismatch in magnitude by as much as 50 %. The Lower Red River (LRR) basin record contains three periods during which there is a grouping of Red River high-magnitude floods: the mid 1700s, the early to mid 1800s and the latter half of the 20th century. Tree-rings indicate that there was spring flooding along both the Red and Assiniboine rivers in AD 1826, 1538 and 1510.

Coring in offshore Lake Winnipeg, receiving basin of waters from the Red River, was designed to sample sites likely to record influx of sediments from the Red River. The results of this assessment are presented in this Open File. Several layers of enhanced silt, 1-4 cm thick, with 6-15 % more silt than background are present in the cores. Silt excursions identified in one or more cores coincide with 5 out of the 7 most extreme floods ($\geq$ 3000 m^3/s) of the past two centuries, including 1997/1996, 1979, 1950, 1852/1850, and 1811, as well as a moderate flood in 1966 (2500 m^3/s) (Figure 3). However, the cores do not contain excursions for floods in 1861 and 1826, the fourth and first largest, respectively, on record (Figure 3). The tendency of the sediments to record both moderate and major floods, while failing to record all major floods in all cores, suggests that the sediments provide at best an incomplete record of moderate to major floods. Nevertheless, this record indicates that ten pre-1800 flood events may have occurred since AD 1100-1050.

Following the 1997 flood, a 1-3 cm thick flood bed was observed to occur in floodplain lakes (Medioli, 2003). A study of select lakes involving chronological, palynological, grain size, mineralogical and geochemical data did not identify a flood record (Medioli, 2001). Floodplain alluvial deposits at several sites along the Red River were examined to determine if these sediments hold a record of flooding. The chronology of the sediments was established using radiocarbon dating of charcoal (Brooks, submitted, c) and optical dating (Lian and Brooks, *in preparation*). Lateral and vertical sedimentation rates of the floodplain were determined, although flood events were not recognized.

Archaeological sites in Winnipeg have also been assessed from a flood record perspective (Kroker, 1997; 1998). In areas that experience repeated sedimentation episodes, the cultural horizons may serve as temporal markers between succeeding depositional events, especially when there has been insufficient time elapsed for the formation of a soil horizon. In addition, the cultural identification of the occupants provides a broad temporal range for the occupation, while radiocarbon dates obtained from organic materials within the archaeological horizon can provide more exact dating of the previous flood episode. Archaeological investigations at the junction of the Red and Assiniboine Rivers suggests that at least ten flood episodes occurred within the past 600 years, although this record has yet to be integrated and compared with the record of known floods.

SAMPLING AND ANALYTICAL METHODS

From the central portion of Netley Lake (Figure 2) six cores were collected. Multiple cores were needed to provide sufficient material for a range of analyses and to retain the option to establish core-to-core correlation of sediment properties. Sampling was conducted in February 2001 from the ice using a Livingstone corer, capable of collecting a core 1 m in length (Table 1). The cores were sealed, labeled and transported to Manitoba Geological Survey in Winnipeg, where they were refrigerated and split in half longitudinally. One core (06 NL) was selected on the basis of apparent integrity, and one half of the core was sliced into 103 1-cm subsamples for grain-size analysis, while the other half was sliced into 21 5-cm subsamples for macrofossil analysis. Subsamples were sealed in plastic bags. Subsequently, the subsamples from this core were analyzed for grain-size and macrofossils.

Grain-Size Analysis

Prior to analysis, the wet 1-cm subsamples were soaked in a sodium metaphosphate solution (10 gm/l) for a minimum of 72 hours at the GSC Sedimentology Laboratory in Ottawa. Each sample was placed in a beaker, further diluted with sodium metaphosphate and suspended using a propeller. Subsamples were obtained with disposable syringes and injected into the particle size analyzer.

Grain-size analyses were completed using a Lecotract LT-100 particle size analyzer. This equipment is based on the scattering of light rays as they are transmitted through particles suspended in a fluid (Jonasz, 1991). Mean values were calculated mathematically by the method of moments (Allen, 1981). Results are reported as weight percentages for 13 classes of silt and clay including <1μm, 1-2μm, 2-4μm, 4-8μm, 8-16μm, 16-32μm, 32-44μm, 44-63μm, 63-88 μm, 88-125 μm, 125-180 μm, 180-250 μm and 250-355 μm (Table 2). Clay is defined as material finer than 4 μm in diameter, silt as material with a diameter of 4 to 63 μm and sand as a material with a diameter of 63 to 2000 μm.

Analytical accuracy was monitored through the analysis of an informal, non-certified laboratory standard, referred to as Chittick (Table 3). Duplicate samples were not analyzed. Throughout analysis of the Netley core, the mean value of the laboratory standard was consistent and the standard deviations low, indicating consistent laboratory conditions and good reproducibility. However, caution should be exercised when comparing results from these analyses to results from other laboratories, particularly laboratories using different analytical equipment.

Macrofossil Analysis

Macrofossils were recovered from the core by Paleotec Services in Ottawa. The initial volume of the wet sediment samples was estimated using a wet displacement technique. Using warm tap water, the remaining sediment was sieved through nested 40, 60 and 230 mesh Tyler sieves (mesh openings of 0.425, 0.25 and 0.063 mm, respectively). All organic and sediment material greater than 0.25 mm was examined using a binocular microscope and plant and animal fossil remains were isolated for identification and potential radiocarbon dating. The retained plant and insect macrofossils were counted, and identified with the aid of a microscope. To verify the vascular plant identification in the samples, the fossils were compared to the GSC reference collection of vascular plants. Macrofossils isolated for dating were air-dried, weighed and placed in sterilized glass vials with aluminium foil-lined caps prior to submission.

Three *Scirpus* seed samples (depths of 100-103, 85-90 and 70-75 cm) were sent for radiocarbon dating at the Lawrence Livermore National Laboratory, Center for Accelerator Mass Spectrometry at the University of California. AMS dating was preferred over conventional radiocarbon dating for its ability to date small samples (0.5 mg) with high accuracy. Well-preserved macrofossils from plants that derive their carbon from the atmosphere could therefore be selected for dating, thus avoiding problems such as the hard-water effect and the reworking of older sediments (Telka, 2000).

RESULTS

Grain-Size Analysis

Complete grain-size analysis of the 103 samples provides a detailed description of the stratigraphic changes in the clay-silt-sand distribution (Table 2; Figure 4). The whole-core mean grain size is 25 μm (Figure 5) and classified as medium silt (4-63 μm). Mean grain size ranges from 10 and 57 μm. All of the sediment was finer than 355 μm, with whole core averages of % clay-silt-sand being 25-65-10, respectively (Figure 5). One of the most striking shifts occurs at 82 cm with the onset of an up-core increase in silt, followed closely by an abrupt decrease in clay and sand at about 80 cm. Below this depth, silt content is lower than in the rest of the core, and clay and sand content are higher than in the rest of the core. A 2-cm thick layer of increased sand occurs between 88-90 cm depth. Above this depth, silt content follows an abruptly variable pattern of cm-scale increases and decreases. This pattern is mirrored somewhat by sand content, whereas clay content exhibits a more gradual trend of a mid-core increase followed by a gradual decrease towards the upper portion of the core. With the exception of the top 10 cm, silt content gradually increases up-core from about 75 cm. An abrupt up-core increase in clay and a decrease in sand are observable at 22 cm. An abrupt shift in silt content was not noted at this depth. Within this middle interval, two cm-scale layers of significantly higher sand content occur at depths of 72-77 cm and 25-27 cm. A layer of significantly greater sand occurs between 1 and 6 cm depth. Within this layer, clay content is greater, although it begins to increase at 8 cm depth, rather than at 6 cm.

Macrofossil Analysis

Floral and faunal macrofossil abundances for the core are presented in Tables 4 and 5, respectively. Macrofossil abundance includes counts of both plant and animal remains. The floral fossil remains associated with each interval in the core, along with occurrences of other miscellaneous material including charcoal/charred organic remains, twigs, bark, deciduous leaves, vivianite and modern plastic and paper are presented in Table 4. All data tables include the depth (in cm) of the sampling interval below the top of the core and macrofossil abundances of all species (including common names) at each depth. In addition, each species is categorized under a heading that designates habitat. Floral species are categorized as aquatic, shoreline/terrestrial, trees/shrubs or other, whereas faunal species are categorized as aquatic/hygrophilous, terrestrial or other. The number of macrofossil, seed, organic matter and charcoal fragment identifications made in each 5-cm increment are shown in Figure 6. Down-core variations in floral and faunal macrofossil species abundances are illustrated in Figures 7 and 8, respectively.

Total macrofossils, seeds, coarse organics and charcoal fragments

Total macrofossil abundance is highest near the base of the core, reaching a maximum count of 3523 in the 85-90 cm increment (Figure 6). Above 80 cm, the counts are consistently less than about 1000, except for the uppermost 5-cm increment where counts reach 2555. Two additional smaller peaks occur at approximately 25-30 cm (1000 identifications) and 60-65 cm (1032 identifications). All four peaks in abundance can be attributed to ostracode valves. The basal increase at 85-90 cm is contributed to by *Chara/Nitella* type oogonia (freshwater algae), Spongillidae (freshwater sponges) and Chironomidae (larval midges).

Macrofossil seeds are more abundant in the basal sediments (80-103 cm), with a maximum abundance of 72 seeds at 90-95 cm (Figure 6). A few smaller peaks at 50-55 cm, 40-45 cm, 25-30 cm and 0-10 cm do not appear to correspond with the smaller peaks in total macrofossil content.

The organic content in the sediments was approximated by measuring the volume of coarse organic material (>250 μm) as a percentage of the total sediment volume (Figure 6). Percent organic content varied from 3 % (10-15 cm) to 79 % (90-95 cm). The basal sediments (80-103 cm) yielded the largest amount of organic matter (50 to 79 %), diminishing up-core with three smaller increases at 65-70 cm, 25-35 cm and 5-10 cm (32%, 33% and 14% respectively). These trends roughly correspond with those for total macrofossil content. The number of charcoal and charred organic remains identified in the core is low, except for a spike at 75-80 cm (Figure 6).

Floral macrofossil taxa

Plant macrofossils observed in the core are *Scirpus* (bulrush) and *Typha* (cattail) seeds, *Chara/Nitella* type oogonia, *Zannichellia palustris*, *Myriophyllum exalbescens* and net-veined leaves (Figure 7). The most common plant macrofossils are *Scirpus* and *Typha*. *Scirpus* seed abundance is greatest near the base of the core (80-103 cm) with the highest occurrence (~50) at 90-95 cm. *Typha* seed abundance shows a similar increase in the basal sediments, as well as peaks at 50-55 cm, 15-35 cm and 5-10 cm. These peaks coincide with peaks in organic content (Figure 7).

Down-core variation in *Chara/Nitella* type oogonia (freshwater algae) abundance is also shown in Figure 7. *Chara/Nitella* remains are present in low numbers throughout most of the core, with an abrupt increase in abundance the between 80-90 cm (up to 574 oogonia). Also noteworthy in the floral fossil assemblage is an increase in the macrofossil seeds of *Zannichellia palustris* (horned pondweed) and *Myriophyllum exalbescens* (northern water milfoil), which also exhibits its first occurrence in the sediments at 85-90 cm.

Faunal macrofossil taxa

The fauna can be categorized as either aquatic/hygrophilous (living in or in the vicinity of water) or terrestrial. Faunal remains in Netley Lake are more abundant than plant macrofossil remains and are dominated by Spongillidae (freshwater sponges), Tubellaria cocoons (flatworms), Bryozoa statoblasts (moss animals), Chironomidae (midges), Coleoptera (aquatic beetles), *Daphnia* ephippia (water fleas), Ostracoda valves (ostracodes), Gastropoda (mollusc snails) and Pelecypoda (mollusc clams) (Figure 8).

Ostracoda valves are far more abundant in the core than any other faunal macrofossils identified, ranging up to 2000 valves. However, the bottommost portion of the core (90-103 cm) is barren of Ostracoda valves. This is followed up-core by an abrupt increase at 85-90 cm to ~1000 valves. Three other increases in abundance of more than 500 valves occur at depths of 55-65 cm, 25-30 cm and 0-5 cm. The most striking increase occurs in the top five cm of the core, were abundance increases from about 200 to nearly 2000.

Spongillidae (*Spongilla* type) are abundant near the bottom of the core, with a maximum abundance of 600 for the 85-90 cm interval (Figure 8). A dramatic decrease in Spongillidae abundance occurs at 75-80 cm, dropping to less than 25 cells, and remaining extremely low in abundance above this depth.

Chironomidae head capsules are most abundant at the base of the core, with a maximum abundance of 500 noted for the interval 85 to 95 cm (Figure 8). Immediately above this interval, abundances drop to less than 200, and have a gradual up-core decline to the top of the core. Three other, less significant, peaks in abundance occur at 65-70 cm, 25-30 cm and 0-5 cm.

Daphnia ephippia are in low abundance (< 100) in the lower half of the core (Figure 8). Numbers of ephippia dramatically increase above 60 cm, reaching a maximum abundance of 420 ephippia at 55-60 cm. Above this interval, abundances decline.

Tubellaria exhibit trends similar to those observed for the sponges, with maximum abundances in the lower portion of the core, followed by a significant decrease in abundance around 80-85 cm and only minimal abundance above 70 cm (Figure 8). The main differences are that the decrease is more gradual in the case of Tubellaria and they increase somewhat in the top 10 cm of the core, whereas Spongillidae do not.

Gastropoda and Pelecypoda (freshwater mollusc) shell abundance is relatively low throughout the core, except for three peaks at 85-90 cm, 65-70 cm and 0-5 cm (32, 117, and 73 shells, respectively) (Figure 8).

Three peaks in Bryozoa statoblast abundance are noted at 85-90 cm, 55-60 cm and 25-30 cm, with the largest increase occurring at 55-60 cm with 57 statoblasts counted (Figure 8).

Exoskeletal fossil remains of aquatic or hygrophilous insects include Coleoptera (water beetles) (Figure 8), Corixidae (water boatmen), Dytiscidae (predaceous diving beetles), Hydrophillidae (water scavenger beetles), Hydraenidae (minute moss beetles), *Stenus* (rove beetles) and Helodidae (marsh beetles). Ephemeroptera (mayflies), Trichoptera (caddisflies), Tipulidae (crane flies) and Chironomidae (midges) represent the aquatic immature forms. With the exception of Coleoptera and Chironomidae these taxa are not presented graphically, as their abundances are extremely low.

Plastic

The presence of plastic debris in the uppermost 25 cm of Netley Lake sediments suggests that these sediments are young, presumably no older than the mid-20th century according to authorities on cultural debris in the area (P.Rider, personal communication with Brooks, in Brooks, submitted, c).

AMS Radiocarbon Dating

In order to avoid the hard-water effect exhibited by some aquatic plants (Andree et al., 1986), emphasis was placed on the selection of terrestrial macrofossils for AMS dating. Macrofossil seeds from aquatic submergent plants such as *Potamogeton* (pondweed) were avoided. Tornqvist et al. (1992) found that fruits of *Potamogeton* spp. as well as other submergent aquatics fully record the hard-water effect and were capable of utilizing a carbon source derived from 'old' carbon. Seeds of the aquatic emergent *Scirpus* spp., were chosen for AMS dating based on the plant's ability to utilize atmospheric CO_2 for photosynthesis.

Radiocarbon dates and related information for the three *Scirpus* seed samples obtained from the core are presented in Table 6. The data table includes the core number, the depth (in cm) of the sampling interval below the top of the core, the age in radiocarbon years, the possible calibrated ages, the taxon, and the degree of preservation. As the core was analyzed in 5-cm increments, or 3-cm for the lowest increment, the depth of macrofossil identification is estimated as the mid-point of the interval.

Calibration of radiocarbon dates

Radiocarbon ages were calibrated in order to provide dates in calendar years (years AD) for use in developing a chronological model for the cored sediments. The calculation of radiocarbon ages assumes that the specific activity of ^{14}C in atmospheric CO_2 has been constant with time, when in fact, it has varied (e.g. Stuiver and Braziunas, 1993). This variation has been modeled by measurement of the radiocarbon age of tree rings of known age (determined by dendrochronological means) and has allowed for the development of decadal calibration datasets used for conversion of radiocarbon to calibrated ages. Linear interpolation of the data points of the calibration dataset is used to create calibration curves of calibrated age (x-axis) versus radiocarbon age (y-axis). The conversion software CALIB4.1 (Stuiver and Reimer, 1993) was used to make this conversion and to calculate the probability distribution for the true age of the sample.

Calibrated ages were determined using the intercepts-with-curve method, in which ages are given by the intercept of the calibration curve with the radiocarbon age (Stuiver and Reimer, 1993). With this method, multiple intercepts, and hence multiple ages are possible. The two sigma (2σ) errors or 95 % confidence levels are determined from the intersection of the calibration curve with the $\pm$2SD values (two times the standard deviation) of the radiocarbon age. The uppermost *Scirpus* seed (65-70 cm) produced a calibrated age of AD 1950, or an age range of AD 1700 to 1954 with errors. As the C-14 values did not show evidence of nuclear testing, the upper boundary is fixed at 1954, which is the year before nuclear testing began to influence C-14 values (Stuiver, 1970). The middle seed (85-90 cm) produced three possible calibrated ages with a 200-year span including errors, while the lowermost seed (100-103) produced an age of AD 1650 $\pm$ 30 years.

The two lower samples exhibit an age inversion, which could be due to reworking of the middle seed. The preferential incorporation of carbonate material by the larger species (middle seed) of the two seeds is a possible explanation. The uppermost (65-70 cm) and lowermost (100-103 cm) dated *Scirpus* seeds were small-form species, whereas the middle (85-90 cm) dated seed was a larger species, known as *Scirpus* cf. *fluviatilis* or gray river bulrush. Adams (1985) has shown that certain aquatic macrophytes can utilize carbon from CO_2 in the interstitial water of sediment and that species of larger plants have an extensive and continuous system of internal air spaces in their tissues and are capable of re-fixation of CO_2 derived from respiration or CO_2 uptake by the roots in sediment. Smaller plant species may be incapable or less able to re-fix respired CO_2 or to absorb it through the sediments. Hence, the age of the middle seed (85-90 cm) could be in error and hence could be the source of the inversion. Additional dating would need to be done to confirm this.

ANALYSIS

Overall, there is a striking resemblance between % coarse organics and % sand down-core profiles (Figure 9). All increases in % coarse organics are accompanied by increases in sand. It may be that the material classed as sand is actually comprised of coarse-grained organics. Without the aid of total organic carbon analysis it is impossible to determine what proportion of the material classed as sand is clastic. Hence, the origin of layers of increased sand cannot be currently assessed. Likewise, the origin of shifts in silt and clay content cannot be assessed.

Zonation

The Netley Lake core can be subdivided into four zones based on grain size, seed abundance and percent coarse organic matter (Figure 9).

Zone 1 (84-103 cm)

The higher organic content (50-79 %) and higher seed abundance characterized by this zone imply that Netley Lake was a shallow closed basin during this time. This is supported by the dominance of emergent *Typha* sp. and *Scirpus* and the excellent preservation of seeds, which suggests minimal transport. The aquatic emergent *Typha* sp. grows in shallow water, often forming large conspicuous stands along margins of water bodies. Similarly, species of *Scirpus* inhabit wet marshes and borders of lakes and ponds. Both prefer quiet water conditions with low turbulence, and a minimal influx of medium- to coarse-grained sediment. It is unlikely that these taxa would proliferate under conditions of greater sand influx. Hence, the greater sand content of this interval is likely comprised of organic material rather than clastics.

Both the sponge fauna and emergent aquatic flora are used to infer that the early basin was shallow and contained standing or slow-moving waters. Consistently high numbers of Spongillidae in the basal sediments indicate Netley Lake was a stable aquatic environment, with clear, low calcium water and abundant microorganisms for Spongillidae to feed on. Under these favorable conditions Spongillidae will proliferate, encrusting available surfaces (Frost, 2001). Spongillidae are filter feeders and are not capable of withstanding high levels of turbidity, as suspended sediments tend to block the canal system of Spongillidae.

This zone is characterized by a gradual up-core increase in *Zannichellia palustris*, Spongillidae, Chironomidae, Tubellaria, Bryozoa and Coleoptera, as well as more abrupt increases in *Chara/Nitella, Myriophyllum exalbescens,* Ostracoda, Gastropoda and Pelecypoda. This trend is likely the result of the gradual establishment of stable aquatic conditions and a gradual deepening of lake waters. The more abrupt increases of specific taxa are likely due to the fact that some taxa will not proliferate until a narrow range of environmental conditions are met.

Zone 2 (35-84 cm)

The boundary between zones 1 and 2 is very distinct and is characterized by abrupt or more gradual decreases in nearly all of the taxa examined, accompanied by a shift from clay-rich sediment to silt-rich sediment (up to 85 % silt). Abrupt up-core decreases in *Typha* sp. and *Scirpus* seeds at 70-80 cm suggest that the environmental conditions in the lake changed at this time, becoming more turbulent. The abrupt decrease in Spongillidae abundance at 75-80 cm could have been triggered by an abrupt change in the water flux and sediment load entering the lake. Similarly, Tubellaria (flatworms) abundances decrease dramatically, although somewhat more gradually (over the interval 70-85 cm), supporting a rapid environmental change. The more robust nature of Tubellaria is reflected in the more gradual up-core decrease and in the partial recovery near the top of the core. Chironomidae (midges) are excellent indicators of water quality and have been used as indicators of recent eutrophication of lakes (e.g. Warwick, 1980; Brodin, 1982; Wiederholm and Eriksson, 1979), however, they are also sensitive to changes in lake temperature, acidity, and salinity. An abrupt influx of water from a previously non-contributing source could alter the temperature, acidity or salinity of the lake waters. The sharp decline in Chironomidae identifications at 80-85 cm suggests that a significant change did occur at this point and the continuing gradual decline above this depth suggests that favourable conditions did not return. Coleoptera beetles, although in low abundance (< 15) throughout the core, tend to mimic many of the trends exhibited by the midges.

The proliferation of *Daphnia*, known to thrive in times when other taxa experience losses, above this depth, supports the concept that a change in conditions caused many taxa to diminish. Both Bryozoa and *Daphnia* attain their greatest abundance in zone 2, and as their reproduction is aided by the production of asexual buds (Bryozoa statoblasts) and resting eggs (*Daphnia* ephippia) in response to deteriorating environmental conditions. *Daphnia* ephippia production occurs when environmental conditions within their habitat deteriorate, for instance overcrowding, lack of food or oxygen depletion (Korhola and Rautio, 2001). In general, species of *Daphnia* are sensitive to changes in lake trophic state, predation, lake transparency and acidification. The increase in abundance at 60-65 cm could be in response to any one of these environmental conditions that are detrimental to other taxa, but not to *Daphnia*. The increased production of *Daphnia* ephippia could be attributed to decreases in water transparency caused by increased turbidity. Bryozoa are most common in still or slow-flowing waters, with high densities of phytoplankton and suspended organic matter.

However, unlike other taxa present, Bryozoa exhibit different trends above a depth of about 80-85 cm, obtaining peak abundance mid-core, which suggests that Bryozoa productivity is unrelated to conditions that control the other taxa in the lake. An examination of grain size results revealed no correlation between a specific grain size category and Bryozoa abundance.

Gastropoda and Pelecypoda (Mollusc) shells greatly increase in numbers at 65-70 cm, suggesting a change in pH to more alkaline conditions. Molluscs are abundant in calcareous sediments and, like Ostracoda, are better preserved in calcareous, fine-grained sediments. The occurrence of peak abundance at 65-70 cm suggests either an inflow of calcareous material at this time or a change in environmental conditions such as nutrients or predation that promoted the growth and proliferation of the molluscs. Without knowledge of detrital versus non-detrital carbonate proportions, it is difficult to make a conclusion on this point. Detrital calcareous material in the region is derived from tills formed through glacial reworking of Paleozoic carbonates (calcite and dolomite) that comprise much of the shoreline material of the lake. Assuming riverine input to the lake existed at this time, a decrease in riverine input could cause the relative proportion of shoreline-derived material to increase, thus increasing the carbonate content in the lake. A similar peak in Ostracoda abundance occurs at 60-65 cm. The high percentage of clay and fine silt, with very little sand, provides the best substrate for Ostracoda and allows them to proliferate.

Zone 3 (10-35 cm)

Percent clay decreases slightly up-core, with an abrupt increase at 21 cm, whereas silt content remains relatively unchanged throughout this zone. Percent sand increases and peaks at ~27 cm, followed by an abrupt decline at 21 cm. This increase in sand is coincident with an increase in Ostracoda abundance, implying that the coarse-grained fraction of the sediments is largely comprised of organics. Macrofossil seed abundance and organic content increase between 25-35 cm and decline abruptly in the uppermost portion of this zone at 10 cm. The increase is comprised of significant increases in *Typha* seeds, net-veined leaves, Ostracoda valves, Chironomidae, Bryozoa, and Coleoptera, and could have been caused by a temporary shift to less turbulent conditions.

Zone 4 (0-10 cm)

Unlike the preceding zones, silt content decreases and sand and clay percentages increase in zone 4. The increase in sand is attributed to a significant increase in Ostracoda abundance. In addition to Ostracoda, increases in mollusc shells (Gastropoda and Pelecypoda) are also observed in this zone, beginning around 10 cm although most evident in the top five centimeters. Increases in mollusc shells suggest either an inflow of calcareous material or a change in environmental conditions such as nutrients or predation that promoted the growth and proliferation of the molluscs.

DISCUSSION

Dating of the Abrupt Change in Sedimentation

The abrupt decreases in most macrofossils, accompanied by significant shifts in clay, silt and sand at 84 cm indicate a major environmental change (Figure 9). The limited and problematic chronological data is not very useful in constraining the age of this event. The lowermost dated seed (100-103 cm) provides an age of ~AD 1650, indicating that the shift at 84 cm occurred some time within the past 350 years. Given the unknown rate of sedimentation within zone 1, it is not reasonable to estimate how long after AD 1650 the shift occurred. The middle dated seed, whose age was inverted with the lowermost seed, does not constrain the age of this contact. The uppermost dated seed provides a wide age range that also does not constrain this boundary.

Possible Mechanisms for the Abrupt Change in Sedimentation

Given the large volumes of sediment transported by the Red River to Lake Winnipeg every year, a sudden connection of flow from the Red River to Netley Lake would have caused a sudden influx of coarser sediment that could have caused the abundance of quiet-water taxa to decline. This sudden connection to the Red River could have been caused by construction of a cut in 1913-14 between the Red River and Netley Lake to provide an alternative route for small boats traveling to the western shore of Lake Winnipeg, to the opening of the crevasse splay in 1970 along the dry bed of the former cut, or to an earlier undocumented connection to the river. The recent history of the narrow opening between the Red River and the eastern side of Netley Lake is documented by Manitoba Public Works records and National Air Photo Library images. Public Works records pertaining to Netley cut (Table 7) indicate that a narrow cut was dredged between the Red River and Netley Lake in 1913-14, and within a year, water flow through the channel caused it to widen. In 1916-17, a bridge was built to facilitate crossing of farmers who owned hay lands to the north. Attempts to close the channel began in 1919-20 with the construction of a wall at the junction between the cut and the Red River, and culminated with the construction of a dam in 1923-24. The records imply that the channel was sealed with the completion of the dam, although additional fill was added around the dam in 1924-25, 1926-27, and 1948-49. Air photos in the vicinity of the cut were examined and observations from each summarized in Table 8. The earliest of these photos, taken in 1926, shows a structure on the cut, likely the dam, although it is not evident whether or not the structure is blocking the flow of water. However, air photos from 1929 and 1946 clearly indicate that the dam was blocking the flow of water through the cut, and illustrate the gradual infilling of the cut with sediment and vegetation. These records indicate that flow in the cut was terminated sometime between the dam's construction in 1923-24 and the time of the 1929 air photo. Air photos taken following the Red River flood of 1950, show floodwaters overtopping the levee between the river and Netley Lake in many places, including the former cut, implying that during extreme floods the Red River may have been connected to Netley Lake.

In air photos taken in 1963, 1965 and 1968, the cut is evident only as notches on either side of the levee. Air photos from 1972 (Figure 10) and 1977 clearly indicate a breach in the levee at the location of the former channel, and air photos from 1989 and 1994 reveal a breach that is at least twice as wide as the breach in the 1970's photos, consisting of two distinct, side-by-side channels. Hence, the breach occurred between 1968 and 1972, and was perhaps triggered by a flood that occurred in 1970, having a peak discharge of 2280 m^3/s, perhaps in association with an ice jam. Lake levels were higher beginning in the late 1940's, which caused a reduction of the land area between the Red River and Netley Lake. By the 1970's, much of the land between Netley Lake and the Red River formerly used as hay fields was submerged. Following the 1968-1972 breaching, after which water levels continued to rise, no attempts were made to block the breach.

Although there is documentation of a connection between the Red River and Netley Lake as a narrow channel for 10 to 16 years between 1913-14 and 1923-29, and as a wider (~ 500 m wide) channel for 30 years from 1970 to the present, record keeping began only in the early 20th century and Netley Lake has likely experienced significant change throughout its 1000-year development.

Assessment of the Potential for a Red River Flood Record

Flood events on the Red River may have manifested themselves in Netley Lake, although given the multiple sources of sediment inputs that have not been fully characterized, the nature of potential flood deposits cannot be established. These sources include the suspended sediment load of the Red River, the composition of the levee deposits nearest the breach that connects Netley Lake the Red River, lacustrine fossil production, and the material that enters from the north during periods of high water coincident with storms. Floods on the Red River would likely manifest themselves as layers of silt in Lake Winnipeg, and could potentially manifest themselves as layers of silt or sand in Netley Lake. Unfortunately, layers of sand present in the Netley core examined here appear to be related to increases in the coarse organic fossil content. Analysis of total organic carbon is needed to confirm the origin of these layers, and to assess the proportions of clastic versus organic content of each of the grain size subdivisions presented here.

The connection of Netley Lake to the Red River during the 20th century has been sporadic, opening and closing both by human intervention and natural causes. Therefore, any flood record might only be a partial record, captured during times when the connection between lake and river was maintained. The history of lake closures and openings, documented by public works records and air photos, is limited to observations made about every ten years only for the past century. As a result, it is not clear whether flood events prior to 1950 were capable of overtopping the levee between the Red River and Netley Lake, being governed not only by flood magnitude, but also by climate and possible ice jams. For instance, during drier periods the connection between the lake and river may have been weak, or the dam may have leaked or been breached on occasion. Additionally, the record may be complicated by wind-driven sediment transport from Lake Winnipeg. Without knowledge of these details, as well as the uncertainty in dating the grain-size shift at the zone 1/2 boundary, details on sedimentation cannot be reconstructed.

CONCLUSIONS

The abrupt shifts in macrofossil abundance and grain size evident in the lower portion of the Netley Lake core indicate an abrupt change in sedimentation, perhaps resulting from an abrupt influx of water and sediment. Twentieth century records document two events that caused a rapid influx of water and sediment to Netley Lake from the Red River: construction of a cut between the Red River and Netley Lake in 1913-14 and the breaching of the river levee in 1970. Thus, it is conceivable that other abrupt influxes have occurred in the lake's 1000-year history. A sudden connection to the Red River during a breach could drastically alter the relative contributions of sediment sources to the lake, such that prior to the breach sedimentation might have been dominated by lacustrine sedimentation and shoreline erosion, whereas following a breach sediments from the Red River drainage basin might dominate. The input of sediment from the Red River could cause significant decreases in flora and fauna that prefer quiet, shallow water conditions and increases in those taxa that thrive under stressful times of change. It appears that above the depth of the shift (~84 cm), macrofossil taxa were unable to regain their previous level of stability. Uncertainties in the sporadic history of openings and closures to the river, in the character of the incoming sediments, in the chronology, and in the clastic versus organic content of grain-size variations do not permit an adequate understanding of how floods and other events might be manifested in Netley Lake sediments.

RECOMMENDATIONS

- Coring sites distributed throughout Netley Lake would provide information on spatially variable processes, such as the influx of riverine sediment close to the breach or the influx of material across the barrier island.

- It would be useful to analyze multiple cores close to one another, in addition to multiple cores spaced throughout Netley Lake, to determine whether trends observed in a single core correlate core-to-core.

- Coring to the top of the Lake Agassiz sequence would provide a complete record of sedimentation in Netley Lake. This could help in deciphering the early history of Netley Lake, perhaps providing a long-term history of flooding. Dating of the base of the Netley Lake sequence, if cores are strategically distributed, could provide additional information on timing and processes as the lagoon has shifted southward.

- Core chronology could be enhanced by using Pb-210 dating for the most recent 150 years, and by using strategically placed radiocarbon dates deeper in the core.

- A study of levee stratigraphy could be conducted to obtain a better understanding of potential inputs to Netley Lake from erosion of the levee deposits.

- Sampling of the suspended load of the Red River during flood and non-flood times is required to better characterized riverine inputs to Netley Lake.

- Sedimentological analysis of the cores would further aid the interpretation of the grain-size data.

- Organic content of the lake-bottom sediments could be characterized by analysis of total organic carbon (TOC), to determine the extent to which grain-size classes are comprised of organic versus clastic sediments.

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Table 1. Locations and lengths of cores collected from Netley Lake

Site No.	Core No.	Latitude N	Longitude W	Water/ice depth* (cm)	Core length (cm)
01TCA0001	01 NL	50.318509	-96.860975	~ 100	~ 100
01TCA0002	02 NL	50.318509	-96.860975	~ 100	~ 100
01TCA0003	03 NL	50.313351	-96.865140	~ 100	~ 100
01TCA0004	04 NL	50.313351	-96.865140	~ 100	~ 100
01TCA0005	05 NL	50.316513	-96.860559	~ 100	103
01TCA0006	06 NL	50.316513	-96.860559	~ 100	103

*Cores were obtained in February when the lake was frozen to the bottom, so value given is ice depth

Table 2. Grain-size data for samples from Netley Lake core (06 NL)

Depth	Size Fraction (µm) (Reported as a percentage < 704 µm)													Grain Size Summary			Mean	St. Dev.
cm	250-355	180-250	125-180	88-125	63-88	44-63	32-44	16-32	8-16	4-8	2-4	1-2	<1	% Sand	% Silt	% Clay	µm	µm
0-1	0.00	0.00	1.58	4.36	6.94	8.44	7.91	18.69	16.30	14.43	12.41	7.24	1.70	12.88	65.77	21.35	26.41	25.88
1-2	0.00	1.42	4.51	8.32	10.68	8.40	5.75	13.66	12.66	12.56	12.38	7.79	1.87	24.93	53.03	22.04	38.22	40.12
2-3	0.00	3.52	6.61	6.91	7.15	6.08	4.81	11.50	12.20	13.81	14.59	9.88	2.94	24.19	48.40	27.41	39.73	45.16
3-4	0.00	3.64	6.77	6.59	6.61	5.49	4.33	10.93	12.13	14.21	15.38	10.70	3.22	23.61	47.09	29.30	38.91	45.29
4-5	0.45	5.09	6.55	5.32	5.69	5.46	4.80	11.77	12.42	14.05	14.91	10.35	3.14	23.10	48.50	28.40	41.22	47.14
5-6	0.44	4.59	6.74	6.45	6.74	5.77	4.71	12.04	12.10	13.21	14.04	9.96	3.21	24.96	47.83	27.21	42.46	48.37
6-7	0.00	0.47	1.74	2.23	3.13	4.35	6.01	20.07	18.51	17.06	15.01	9.18	2.24	7.57	66.00	26.43	20.60	15.93
7-8	0.00	0.41	1.42	1.94	3.07	4.51	5.70	16.36	19.49	19.55	16.12	9.29	2.14	6.84	65.61	27.55	19.08	15.28
8-9	0.00	0.52	1.75	3.00	6.23	10.27	11.43	22.74	15.88	12.15	9.50	5.42	1.11	11.50	72.47	16.03	28.80	24.47
9-10	0.00	0.39	1.33	2.05	3.91	6.90	9.41	22.81	18.03	15.23	12.12	6.58	1.24	7.68	72.38	19.94	23.20	19.18
10-11	0.00	0.00	0.00	0.57	1.84	3.81	7.39	24.91	21.16	18.35	13.93	6.92	1.12	2.41	75.62	21.97	16.02	12.85
11-12	0.00	0.00	0.63	1.65	4.46	10.64	15.36	24.29	14.18	11.79	10.08	5.80	1.12	6.74	76.26	17.00	25.29	20.97
12-13	0.00	0.00	0.34	0.97	2.01	4.58	8.62	25.34	19.58	16.36	12.86	7.53	1.81	3.32	74.48	22.20	17.75	14.40
13-14	0.00	0.00	0.00	0.31	1.11	2.60	5.93	25.26	22.43	18.36	14.04	8.12	1.84	1.42	74.58	24.00	14.25	11.31
14-15	0.00	0.00	0.00	0.00	0.92	2.19	5.14	24.99	22.63	18.63	14.76	8.72	2.02	0.92	73.58	25.50	13.28	10.61
15-16	0.00	0.00	0.00	0.00	0.61	1.85	3.64	19.08	22.97	21.69	17.40	10.29	2.47	0.61	69.23	30.16	11.26	9.06
16-17	0.00	0.00	0.00	0.74	2.15	4.18	8.05	24.98	20.07	17.88	12.96	7.27	1.72	2.89	75.16	21.95	16.73	13.66
17-18	0.00	0.00	0.43	1.04	1.97	4.54	9.40	30.20	19.20	14.56	10.74	6.34	1.58	3.44	77.90	18.66	19.07	14.52
18-19	0.00	0.00	0.54	1.25	2.04	4.02	7.91	29.62	20.32	14.55	11.35	6.75	1.65	3.83	76.42	19.75	18.63	13.86
19-20	0.00	0.00	0.00	0.59	1.69	3.09	5.74	21.05	20.72	19.23	15.79	9.73	2.37	2.28	69.83	27.89	14.15	11.62
20-21	0.00	0.00	0.34	0.95	1.64	2.91	4.83	16.72	19.31	20.64	18.08	11.34	3.24	2.93	64.41	32.66	13.60	10.94
21-22	0.00	0.00	1.44	2.86	6.00	10.23	11.72	20.60	14.67	13.13	11.05	6.62	1.68	10.30	70.35	19.35	26.62	23.71
22-23	0.00	0.37	2.10	4.23	8.78	13.98	14.33	21.85	11.71	9.33	7.76	4.61	0.95	15.48	71.20	13.32	34.37	28.26
23-24	0.00	0.00	1.37	3.76	9.45	15.61	15.61	22.89	10.68	8.39	7.12	4.26	0.86	14.58	73.18	12.24	33.96	27.33
24-25	0.00	0.00	1.45	3.41	7.90	13.53	14.93	24.03	11.76	9.51	7.93	4.64	0.91	12.76	73.76	13.48	31.70	25.95
25-26	1.02	1.70	2.43	4.88	9.51	12.93	12.07	19.27	11.67	9.89	8.41	5.11	1.11	19.54	65.83	14.63	39.79	32.57
26-27	1.23	1.97	2.60	4.86	8.90	11.77	11.05	18.67	12.11	10.58	9.32	5.43	1.51	19.56	64.18	16.26	39.72	33.17
27-28	0.00	1.19	2.32	3.44	6.49	9.70	10.41	21.30	15.19	12.70	10.18	5.89	1.19	13.44	69.30	17.26	30.59	26.37
28-29	0.58	1.07	1.41	2.32	4.21	6.95	9.39	22.80	17.10	14.48	11.32	6.68	1.69	9.59	70.72	19.69	26.76	20.93
29-30	0.53	1.11	1.48	2.47	4.80	8.18	10.59	23.48	16.02	13.10	10.48	6.17	1.59	10.39	71.37	18.24	28.43	22.51
30-31	0.67	1.41	1.84	3.11	6.05	9.89	11.86	23.63	14.49	11.40	9.13	5.37	1.15	13.08	71.27	15.65	32.68	25.73
31-32	0.80	1.54	1.81	2.83	5.19	8.56	11.26	25.97	15.92	11.41	8.66	5.00	1.05	12.17	73.12	14.71	32.08	24.08
32-33	0.55	1.17	1.47	2.19	3.88	6.70	9.92	26.30	17.33	13.43	10.14	5.74	1.18	9.26	73.68	17.06	27.38	20.14
33-34	0.47	1.03	1.24	1.76	3.16	6.13	10.27	26.19	17.14	14.40	10.94	6.03	1.24	7.66	74.13	18.21	25.43	18.42
34-35	1.08	1.88	1.66	1.84	2.82	5.24	9.34	26.52	17.01	14.45	10.93	6.01	1.22	9.28	72.56	18.16	28.62	18.83
35-36	0.17	0.72	0.86	1.12	1.87	3.78	7.41	25.51	20.23	17.04	12.71	6.96	1.62	4.74	73.97	21.29	19.82	14.02
36-37	0.32	0.74	0.89	1.16	1.85	3.56	6.83	24.72	20.80	17.83	13.02	6.96	1.32	4.96	73.74	21.30	19.93	13.67
37-38	0.39	0.86	0.92	1.11	1.81	3.54	6.81	24.63	20.65	17.73	12.98	6.94	1.63	5.09	73.36	21.55	20.29	13.74
38-39	0.49	1.08	1.11	1.28	2.01	3.82	7.18	24.92	20.33	17.14	12.60	6.75	1.29	5.97	73.39	20.64	21.91	14.59
39-40	0.00	0.58	0.89	1.11	1.81	3.51	6.72	24.69	21.20	17.92	13.26	7.03	1.28	4.39	74.04	21.57	18.59	13.28
40-41	0.00	0.00	0.00	0.94	2.04	3.23	5.95	21.94	21.49	19.86	15.22	7.97	1.36	2.98	72.47	24.55	15.18	12.02
41-42	0.00	0.39	1.06	1.45	2.42	4.33	7.05	22.23	20.17	17.81	13.84	7.56	1.69	5.32	71.59	23.09	19.14	14.60
42-43	0.00	0.35	1.15	1.69	2.97	4.92	6.79	18.64	19.62	19.17	15.29	8.03	1.38	6.16	69.14	24.70	19.31	15.61
43-44	0.00	0.00	0.00	1.32	3.27	4.88	6.97	19.50	20.10	19.36	15.28	7.96	1.36	4.59	70.81	24.60	17.00	14.50
44-45	0.00	0.15	0.57	1.73	3.74	5.87	7.75	19.39	18.90	17.86	14.43	7.88	1.73	6.19	69.77	24.04	19.49	16.92
45-46	0.00	0.00	0.00	1.22	3.04	4.53	6.71	21.05	21.68	18.57	13.86	7.63	1.71	4.26	72.54	23.20	16.87	13.83
46-47	0.00	0.00	0.32	0.75	1.08	1.88	3.63	18.68	24.01	22.16	16.64	8.91	1.94	2.15	70.36	27.49	12.87	9.38
47-48	0.36	1.30	1.46	1.36	1.55	2.32	3.97	17.50	21.60	20.98	16.53	9.04	2.03	6.03	66.37	27.60	19.07	11.48
48-49	0.00	0.00	0.47	0.76	1.14	2.09	4.07	18.81	22.26	21.65	17.26	9.43	2.06	2.37	68.88	28.75	13.29	9.91
49-50	0.00	0.00	0.00	0.00	0.74	1.89	3.08	15.58	22.18	23.72	19.70	10.82	2.29	0.74	66.45	32.81	10.47	8.21
50-51	0.00	0.00	0.00	0.00	1.08	2.65	4.18	17.06	19.24	22.31	19.65	11.33	2.50	1.08	65.44	33.48	11.49	9.62
51-52	0.00	0.00	0.50	0.83	1.17	1.70	2.60	11.96	19.70	24.34	21.81	12.60	2.79	2.50	60.30	37.20	11.19	7.75
52-53	0.00	1.22	1.83	2.06	2.65	4.07	7.02	28.36	19.48	13.65	11.30	6.72	1.64	7.76	72.58	19.66	23.68	15.90
53-54	0.00	0.20	0.55	1.11	1.81	2.67	4.55	19.72	21.63	19.76	16.18	9.55	2.27	3.67	68.33	28.00	15.13	11.10
54-55	0.00	0.00	0.76	0.94	1.32	2.11	3.65	16.47	21.24	21.56	18.21	10.84	2.90	3.02	65.03	31.95	13.33	9.68
55-56	0.00	0.39	1.09	1.24	1.56	2.29	3.77	16.61	20.68	20.78	17.79	10.85	2.95	4.28	64.13	31.59	15.12	10.43
56-57	0.00	1.10	1.64	1.65	1.92	2.62	3.95	15.68	20.11	20.50	17.48	10.47	2.88	6.31	62.86	30.83	18.11	11.79
57-58	0.00	0.19	1.09	1.67	2.02	2.76	4.14	16.38	20.63	21.11	17.61	10.09	2.31	4.97	65.02	30.01	15.81	11.22
58-59	0.00	1.00	1.77	1.87	2.16	2.80	3.93	14.77	19.67	20.98	18.03	10.53	2.49	6.80	62.15	31.05	18.36	12.15
59-60	0.00	1.17	2.04	2.10	2.38	3.07	4.32	16.45	20.29	19.81	16.54	9.58	2.25	7.69	63.94	28.37	20.13	13.50
60-61	0.00	0.40	1.33	1.52	1.76	2.33	3.50	15.28	21.96	21.69	17.80	10.13	2.30	5.01	64.76	30.23	15.73	10.29
61-62	0.00	0.00	0.00	0.00	0.86	1.92	3.00	17.38	25.62	22.57	17.01	9.54	2.10	0.86	70.49	28.65	11.14	8.39
62-63	0.00	0.00	0.36	0.81	1.06	1.65	2.89	15.69	24.87	23.35	17.47	9.69	2.16	2.23	68.45	29.32	12.10	8.41
63-64	0.00	0.00	0.00	0.00	0.76	1.82	2.78	14.94	25.46	24.93	17.78	9.53	2.00	0.76	69.93	29.31	10.54	7.76

Table 2 continued

Depth	Size Fraction (µm) (Reported as a percentage < 704 µm)													Grain Size Summary			Mean	St. Dev.
cm	250-355	180-250	125-180	88-125	63-88	44-63	32-44	16-32	8-16	4-8	2-4	1-2	<1	% Sand	% Silt	% Clay	µm	µm
64-65	0.00	0.00	0.00	0.61	1.70	2.72	4.69	20.13	23.96	21.67	15.14	7.99	1.39	2.31	73.17	24.52	13.79	10.46
65-66	0.00	0.00	0.47	1.21	2.56	3.62	4.66	17.21	20.29	21.12	17.17	9.60	2.09	4.24	66.90	28.86	15.17	11.77
66-67	0.44	2.08	2.28	2.00	2.16	2.68	3.67	13.46	18.78	21.97	18.16	9.94	2.38	8.96	60.56	30.48	22.25	13.62
67-68	0.00	1.50	2.16	2.14	2.43	2.99	4.03	14.75	19.57	20.95	17.27	9.87	2.34	8.23	62.29	29.48	20.57	13.61
68-69	0.00	0.00	0.54	1.89	2.65	3.16	4.58	17.93	21.36	20.38	16.48	9.09	1.94	5.08	67.41	27.51	15.98	11.92
69-70	0.00	0.47	1.54	1.74	2.12	2.77	3.89	15.16	20.92	21.75	17.73	9.80	2.11	5.87	64.49	29.64	16.92	11.38
70-71	0.00	0.73	1.63	1.77	2.27	3.32	5.33	20.40	20.37	18.23	15.30	8.66	1.99	6.40	67.65	25.95	19.42	13.58
71-72	0.00	0.51	1.45	1.68	2.50	4.58	8.57	30.43	19.56	13.91	10.15	5.58	1.08	6.14	77.05	16.81	22.39	15.51
72-73	0.00	3.27	5.81	4.25	4.49	5.44	6.45	17.77	15.85	14.66	12.88	7.39	1.74	17.82	60.17	22.01	35.32	34.06
73-74	0.40	4.74	6.34	4.90	5.20	5.73	6.12	16.25	15.25	14.38	12.07	6.93	1.69	21.58	57.73	20.69	41.07	43.71
74-75	0.00	3.48	5.52	4.21	4.41	5.16	6.09	17.78	16.91	15.21	12.45	7.12	1.66	17.62	61.15	21.23	35.09	33.61
75-76	0.62	4.71	4.89	3.68	4.08	4.89	5.84	17.76	17.91	15.72	12.21	6.48	1.21	17.98	62.12	19.90	37.57	34.89
76-77	0.00	3.13	4.85	3.29	3.37	4.21	5.59	20.43	20.40	16.00	11.75	5.95	1.03	14.64	66.63	18.73	31.91	25.88
77-78	0.00	1.55	2.30	1.93	2.13	2.91	4.67	21.66	23.74	18.34	12.88	6.71	1.18	7.91	71.32	20.77	22.28	13.59
78-79	0.00	0.85	1.79	1.71	2.09	3.13	5.46	25.79	23.62	16.42	11.88	6.17	1.09	6.44	74.42	19.14	20.95	13.25
79-80	0.00	0.00	0.00	0.36	1.29	3.11	7.39	33.26	23.17	15.19	9.97	5.29	0.97	1.65	82.12	16.23	16.78	12.03
80-81	0.00	0.00	0.00	0.30	1.15	2.92	7.28	34.24	24.59	15.27	9.15	4.60	0.50	1.45	84.30	14.25	16.81	11.62
81-82	0.00	0.52	1.51	1.44	1.67	2.25	3.58	18.37	27.32	22.04	13.76	6.48	1.06	5.14	73.56	21.30	17.18	10.27
82-83	0.00	0.00	0.41	0.80	1.04	2.96	4.24	12.22	17.61	21.90	21.97	13.35	3.50	2.25	58.93	38.82	9.59	7.95
83-84	1.48	4.08	2.89	2.52	2.85	3.12	3.35	9.36	14.09	19.72	20.74	12.40	3.40	13.82	49.64	36.54	30.05	23.40
84-85	2.09	7.48	4.28	2.97	3.39	3.62	3.41	8.43	12.76	18.23	19.27	11.14	2.93	20.21	46.45	33.34	41.66	47.32
85-86	1.56	6.69	4.62	3.01	3.12	3.34	3.31	8.46	12.67	18.48	20.00	11.72	3.02	19.00	46.26	34.74	38.67	42.36
86-87	1.41	5.37	3.87	2.72	2.84	3.04	3.13	8.42	13.16	19.84	21.36	12.20	2.64	16.21	47.59	36.20	33.79	30.87
87-88	2.40	6.64	4.71	3.74	4.04	4.32	4.33	10.55	13.90	17.13	17.08	9.15	2.01	21.53	50.23	28.24	43.97	49.37
88-89	2.73	9.62	6.90	4.74	4.92	5.22	4.91	9.78	10.92	14.70	15.46	8.16	1.94	28.91	45.53	25.56	56.10	73.71
89-90	1.21	8.40	6.78	3.91	4.16	4.56	4.14	8.99	11.59	16.13	17.78	10.10	2.25	24.46	45.41	30.13	46.87	62.87
90-91	1.24	5.11	4.40	3.50	3.70	4.25	4.93	15.16	16.46	15.86	15.59	8.09	1.71	17.95	56.66	25.39	37.71	35.75
91-92	2.00	6.98	4.98	3.34	3.38	3.68	3.69	8.82	12.55	18.25	19.48	10.62	2.23	20.68	46.99	32.33	42.00	49.58
92-93	1.14	8.20	6.41	2.79	2.76	3.34	3.10	6.99	11.37	18.69	20.95	11.79	2.47	21.30	43.49	35.21	42.24	59.74
93-94	1.96	6.56	4.77	3.22	3.34	3.79	3.91	9.44	12.74	18.26	19.32	10.49	2.20	19.85	48.14	32.01	40.83	45.51
94-95	1.60	5.62	4.55	3.20	3.24	3.72	4.08	10.80	14.21	17.85	18.76	10.24	2.13	18.21	50.66	31.13	37.84	38.04
95-96	2.67	6.60	4.54	3.18	3.19	3.48	3.56	9.17	13.32	18.37	19.12	10.54	2.26	20.18	47.90	31.92	42.26	48.18
96-97	0.46	3.33	5.16	3.30	2.79	3.14	3.14	7.99	13.21	20.64	21.91	12.31	2.62	15.04	48.12	36.84	29.27	26.91
97-98	0.76	2.95	3.35	2.48	2.25	2.46	2.62	7.69	14.56	22.03	22.61	13.02	3.22	11.79	49.36	38.85	25.05	16.41
98-99	0.98	3.48	3.58	2.64	2.41	2.62	2.78	7.86	14.15	21.87	22.42	12.48	2.73	13.09	49.28	37.63	27.52	20.19
99-100	0.77	3.11	3.87	2.93	2.64	2.88	3.02	8.47	14.34	21.48	22.03	11.91	2.55	13.32	50.19	36.49	27.39	21.50
100-101	0.94	3.36	3.73	2.89	2.70	3.02	3.28	9.48	14.95	20.93	21.00	11.29	2.43	13.62	51.66	34.72	26.30	19.47
101-102	1.62	3.70	3.68	3.09	3.06	3.44	3.76	10.90	16.00	19.77	19.05	9.87	2.06	15.15	53.87	30.98	27.08	20.18
102-103	1.45	3.00	3.16	2.74	2.73	3.20	3.69	11.04	16.15	20.48	19.79	10.36	2.21	13.08	54.56	32.36	26.12	17.90

Table 3. Grain-size results for laboratory standard (chittick) run with Netley Lake core (06 NL)

	Size Fraction (µm) (Reported as a percentage < 704 µm)													% Sand - % Silt - % Clay		
	250-355	180-250	125-180	88-125	63-88	44-63	31-44	16-31	8-16	4-8	2-4	1-2	< 1	% Sand	% Silt	% Clay
	0.00	0.00	0.42	1.97	7.14	18.88	22.19	27.93	13.97	5.46	2.04	0.00	0.00	9.53	88.43	2.04
	0.00	0.00	0.44	2.04	7.39	19.16	22.13	27.69	13.79	5.36	2.00	0.00	0.00	9.87	88.13	2.00
	0.00	0.00	0.39	1.80	6.84	18.96	22.24	28.02	14.10	5.60	2.05	0.00	0.00	9.03	88.92	2.05
	0.00	0.00	0.43	1.99	7.18	18.79	21.96	27.69	13.97	5.55	2.11	0.33	0.00	9.6	87.96	2.44
	0.00	0.00	0.60	2.00	7.12	18.31	21.45	27.39	14.11	5.92	2.39	0.71	0.00	9.72	87.18	3.1
	0.00	0.00	0.42	1.99	7.26	18.78	21.85	27.61	13.99	5.65	2.13	0.32	0.00	9.67	87.88	2.45
	0.00	0.00	0.42	1.98	7.17	18.68	21.87	27.74	13.98	5.62	2.20	0.34	0.00	9.57	87.89	2.54
	0.00	0.00	0.42	1.95	7.15	18.71	21.74	27.52	13.91	5.68	2.25	0.67	0.00	9.52	87.56	2.92
Mean	0.00	0.00	0.44	1.97	7.16	18.78	21.93	27.70	13.98	5.61	2.15	0.30	0.00	9.56	87.99	2.44
St.dev.	0.00	0.00	0.07	0.07	0.15	0.25	0.26	0.20	0.10	0.17	0.13	0.29	0.00	0.24	0.53	0.41

Table 4. Floral macrofossils recovered from Netley Lake core (06 NL)

Taxa	Depth (cm)																				
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-103
Aquatic taxa																					
Algal remains:																					
Characeae																					
Chara/Nitella type (oogonia)	6	1			1	2	3	2		1	2			3	7	11	422	777	30	30	17
Non Vascular plants:																					
Bryophytes "mosses"		1		2	1	2		3													
Sphagnum sp.			3			1									1						
Vascular plants:																					
Typhaceae "Cat-tail family"																					
Typha spp.	3	10		5	10	14	5	2	1	2	8	1		1	3	12	6	17	16.5	14	8
Sparganiaceae "bur-reed family"																					
Sparganium sp.																	1				
Potamogetonaceae "pondweed family"																					
Potamogeton sp.	1				1						4fr		1	2	1.5	1fr	4	1	1fr	1fr	3
Zannichellia palustris L.	1				1										0.5		1	7	5	3	2
Alismataceae "water plantain family"																					
Alisma sp.																1					
Sagittaria sp.	1			1											1			2	2		
Haloragaceae "water milfoil family"																					
Myriophyllum exalbescens Fern.																1	6	14			
Hippuris sp.																	1				
Shoreline and terrestrial taxa																					
Fungal remains:																					
fungal sclerotia										2											
fungal 'spheres'						3															
Vascular plants:																					
Poaceae "grass family"	1		1				1								1?					1?	1
Sporobolus sp.					2																
Cyperaceae "sedge family"					1						1fr				1						
Carex trigonous type						1			1												
Carex lenticular type							0.5														
Eleocharis acicularis (L.)R.S.	1			1							1										
Eleocharis sp.					1													1?			

fr=fragment; ?=questionable identification.

Table 4 continued

Taxa	Depth (cm)																				
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-103
Scirpus spp.	2	1			1+fr	4	1.5	2fr			1	4fr	1+fr	9+fr	3		24+fr	33.5+fr	55.5+fr	33+fr	18+fr
Juncaceae "rush family"																					
Juncus/Luzula type		1							1												
Urticaceae "nettle family"																					
Urtica dioica L.	1			1										1							
Polygonaceae "buckwheat family"																					
Polygonum lapathifolium type		2				0.5															
Rumex sp.		2fr	1		1	1				1	1fr				1			1			1fr
Chenopodiaceae "goosefoot family"																					
Chenopodium sp.	1+fr	4fr	1fr				0.5+fr		1fr												
Corispermum hyssopifolium L.						1															
Portulacaceae "purslane family"																					
Portulaca oleracea L.						1			1												
Ranunculaceae "crowfoot family"																					
Ranunculus sceleratus type		1						1	0.5				0.5		1						
Ranunculus aquatilis L.						1															
Brassicaceae "mustard family"																					
Rorippa sp.							1		0.5		1fr										
Rosaceae "rose family"																					
Potentilla norvegica L.															1						
Onagraceae "evening primrose family"																					
Epilobium sp.																				1	
Ericaceae "heath family"		?1																			
Lamiaceae "mint family"																					
Lycopus sp.						1															
Mentha sp.					1	1	1		1		1				0.5						
Plantaginaceae "plantain family"																					
Plantago major L.				0.5		1															
Asteraceae "Composite family"						0.5+fr					1fr										
Artemisia sp.						1															
Taraxicum sp. "dandelion"				1fr										1							

fr=fragment; ?=questionable identification.

Table 4 continued

Taxa	Depth (cm) 0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-103
Trees, Shrubs and other																					
Pinaceae "pine family"																					
Larix laricina (DuRoi)Koch.																					
Picea sp.		2																			
Salicaceae "willow family"																					
Salix sp.								1													
Betulaceae "birch family"					1																
Betula sp.						1															
Rosaceae "rose family"																					
Rubus idaeus L.																					
Prunus sp.		1																			
Unidentified plant taxa:	1fr			1fr	3fr	2fr	1		1		1fr		1	1		1	2				
Charcoal/non-biogenic fragments:																					
charcoal/charred organics	3	2				3	2								2	11		2		1	1
twigs	4						1?														
wood/woody stems	2	2					+		1								5				
bark						+	5	1									2				
net-veined leaves (deciduous leaves)				7	6	17	3	1	7												
coal	2?	1?				3?	1?														
vivianite						4	1														
modern plastic	1	1		2	1																
modern paper						1															
unknown 'a' round object				2	2	7			2	1	4	2							23	10	6

fr=fragment; +=some material present; ?=questionable identification.

Table 5. Faunal macrofossils recovered from Netley Lake core (06 NL)

Taxa	Depth (cm)																				
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-103
Aquatic and hygrophilous taxa																					
PROTOZOA																					
RHIZOPODA																					
Testacealobosia "testate amoebae"						1															
PORIFERA																					
HAPLOSCLERINA																					
Spondillidae "sponges"																					
Spongilla tye				1	1		1		4		1		21		24	78	+	740	380	410	142
PLATYHELMINTHES																					
TUBELLARIA "flatworms" (cocoons)	25	10		1	9	16	10	7	5	9	4	2	2	13	29	63	117	302	213	177	111
BRYOZOA (statoblasts)																					
Cristatella mucedo L.	1						1									2+fr	11+fr	22+fr	9	2	3
Plumatella sp.	4	10	7	10	16	24	11	8	5	5	12	50	28	10	1	6	16	18	9	2	3
Fredericella type		2	2				4			1	6	1		2	3						
ARTHROPODA																					
INSECTA:																					
EPHEMEROPTERA "mayflies"(immatures)	2	2		2	9	6	2		3												
HEMIPTERA "bugs"																					
Corixidae "water boatmen"	2fr	1+fr	3fr	4fr	2+fr	2+fr	1+fr	4fr	2fr	2fr	2fr	2fr	3fr			4fr	3fr		6fr	3fr	
COLEOPTERA "beetles"																					
Dytiscidae "predaceous diving beetles"																1			1		
Colymbetes sp.						1fr		1fr		1fr					1fr			1			
Hydrophilidae "water scavenger beetles"	1																1				
Hydraenidae "minute moss beetles"																					
Ochthebius sp.					1	2	1														1
Staphylinidae "rove beetles"																					
Stenus sp.						2															
Helodidae "marsh beetles"		1									1+fr										
TRICHOPTERA "caddisflies" (immatures)	1	5	3	4	5	8	2	2	2		1	1	1	5	4		4	4	3	3	2
DIPTERA "flies"																					
Tipulidae "crane flies" (immatures)						1															
Tipula sp. (immatures)																		1	1		1
Chironomidae "midges" (immatures)	48.5	24	6	28	81	229	66	37	38	23	37	67	95	241	177	205	204	641	519	360	219

fr=fragment

Table 5 continued

Taxa	Depth (cm)																				
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	100-103
CRUSTACEA:																					
Cladocera "water fleas"																					
Daphnia sp. (ephippia)	10	44	12	39	60	98	92	102	29	137	271	371	322	80	38	52	23	99	68	59	38
Ostracoda "ostracodes" (valves)	1143	267	59	60	215	599	215	81	95	171	337	402	578	190	118	28	1524	1347			8
ARACHNIDA:																					
Oribatei/Acari "mites"																					
Hydrozetidae																					
Hydrozetes type						1					2				1		2	6	7	8	1
Araneae "spiders"																			2		
MOLLUSCA	150fr	47fr	5fr	2fr	10fr	13fr	3fr	7fr	7fr	7fr	9fr	3fr	25fr	fr	7fr		36fr	68fr	1fr		2fr
Gastropoda "snails, limpets"	19+fr	8+fr			1+fr	1+1fr			3fr		1fr		6fr	60			2+27fr	17+68fr	1+fr		
Pelecypoda "clams, mussels" (valves)	24+fr	3+fr			9fr	2+2fr			3				2	81	3+fr		7+fr	27+26fr	1fr		
Other:																					
fish vertebra(e)/bone					3	2							1	4		1	1				1
fish scale	1+fr					1+fr				1											
pupae	1	1																2			
small mammal feces	1fr																				
egg cases/cocoons (tan whole)	39	19	1	8	26	32	14	5	10	6	29	3	8	15	11	25		181	10		3
immature soft-bodied insects	37	35	18	18	11	27	11	15	11	9	26	14	18	31	42	129	48	177	191	241	73
Terrestrial taxa																					
ARTHROPODA																					
INSECTA:		2		3fr		2	3fr			1fr		1	1			2fr		3fr	3fr	5fr	2
HEMIPTERA "bugs"			1																		
HOMOPTERA "cicadas, hoppers, aphids..."																					
Cicadellidae "leafhoppers"																1		1			
COLEOPTERA "beetles"		2			3	4	3		1	1	1	4	6	2	4	13	7	12	7	5	2
Staphylinidae "rove beetles"						1	1									1			1	1	
Aleocharinae	1	1	1	1			2		1						1			2			
Curculionidae "weevils"																		1			
DIPTERA "flies"	2+p	3	1	1	2	1+p	1	2		1	1			2	4+p	16+p	7	10+p	10+p	9+p	9+p
HYMENOPTERA "wasps and ants"	1	1			2	1												3	1	1	
Ichneumonoidea	1					3	2							1		2	2				
Ichneumonidae																			1		
ARACHNIDA:																					
Oribatei/Acari "mites"	1	2		1			1	1							0.5		2	1			7.5

fr=fragment; p=puparia; +=some material present.

Table 6. Radiocarbon dates on Scirpus seeds obtained from Netley Lake core (06 NL)

Core No. and Depth (cm)	Lab No.	Radiocarbon Age (yrs BP)	Possible Calibrated Age* (AD)	Taxon	Preservation
06 NL 65-70cm	CAMS-84563	70 ± 45	1950 (1700-1954)	*Scirpus* sp. seed	Very good - bristles intact Small seed
06 NL 85-90cm	CAMS-84564	330 ± 40	1520, 1570, 1630 (1450 - 1650)	*Scirpus* sp. seed	Very good - bristles intact Medium-size seed
06 NL 100-103cm	CAMS-84565	250 ± 50	1650 (1620 - 1680)	*Scirpus* sp. seed	Very good - bristles intact Small seed

*Calibrated using CALIB4.1 software by Stuiver and Reimer (1993). The first set of values are the possible calibrated ages, while the values in brackets are the (2 sigma) minimum and maximum ages. Values have been rounded to the nearest decade.

Table 7. Manitoba Public Works record of Netley cut and lake

Fiscal year	Dollars allocated: Dredging	Construction & improvements	Other repairs	Remarks
1913-14	$215.29			Connecting Red River with south end of lake by a dredged cut 285 ft. x ? x 7 ft. water. Dredge #202 in clay casting over 6,645 cu.yds. Cost of work given as $917.24 or 14¢/yard.
				Following a stong wind on Lake Winnipeg, current in dredged channel generally follows the rise in the Red River (and rapidly increased the width of cut following construction). The flow into Netley Lake is gradually balanced by other water received in the lake through Salamony's Channel.
1916-17		$699.35		It became necessary to build a pile trestle bridge for a few settlers who owned hay lands north of cut. It illustrates the strength of the occasional currents here that boats were wrecked on bents of the bridge and two parties were drowned.
1919-20		$710.69 $853.90		Attempt to close cut by wall at river, single piling and sheet piling, adding some fill with Dredge #201. Red River subsequently washed around the ends of this.
1921-22			$522.90	Bridge repairs to several bents, which were scouring or destroyed by ice. River wall yielding.
1922-23			$1020.44	Temporary bridge, making use of pontoons between undestroyed portions of bridge.
1923-24		$2723.02		Dam begun at bridge site as single row piling with sheet piling 30 ft. long. Attempting to manoeuver plant around ends of "river wall", which, however, was hampered by wreck of a scow of the Lake Bar Sand & Gravel Co. Old scow of Department was also sunk along the new dam wall and close to same; scour under wall and scow. About 30 cords of stone were dumped.
1924-25		$791.10		Soundings give 27 ft. of water at L.W. Sand bags and willow Mattress used to choke cut at wall. Vehicles crossing on old Departmental scow deck.
1925-26		$2497.49		6" T. & G. Fir sheeting, some 32 ft. long, driven on east side of Dept. scow. Intention to fill between walls.
			$188.28	Balance of estimate to appear as re-vote $1,000. Dr. Dynamiting of upper portion of sunken barge of L.B.S. & G. Co. (provided by Marine Dept.)
1926-27		$5, 410.91		Filling around wheat pile structure, const. of two walls. Dredge "Red River" removed 13, 594 cu.yds. silt at .22 inc. material placed by #202 - 8,880 yds. At .27 (40¢ aver.)
1948-49	$3341.54			Dredge "Red River" pumped some 1,400 cu.yd. suction dredge measurement, clay and silt, from Red River channel opposite into cofferdam as additional backfill. Dredge operated here from Oct.6 to 14 at cost of $2.38/cu.yd.
			$643.80	Due to lumber decay of anchorage system, a 6" steel channel was placed along outside of pile walls and tied together with 1" steel tierods. Work was supervised by a member of District Office. (Two feet of fill was placed by the Departmental Dredge "Red River.")

Table 8. National Air Photo Library images of Netley cut and breach

Date	Air photo #	Observations
1926	FA.23-9	Cut between Red River and Netley Lake present; washed out wall at Red River present; dam or bridge with road crossing observable on cut just west of wall at Red River; water contacts dam or bridge on both sides, not obvious whether or not there is any flow beneath structure.
1929 - Oct. 13	A.1962-84	Cut between Red River and Netley Lake present; washed out wall at Red River present; dam is clearly blocking the path of water through Netley cut; sediment clearly flanks both sides of the structure
1946 - Aug. 22	A10491-33	Cut between Red River and Netley Lake present; washed out wall at Red River present; dam is clearly blocking the path of water through Netley cut; sediment flanks both sides of the structure and fills in a greater proportion of the cut than in 1929 photo; shrubs and/or trees growing on former Netley cut bed on Red River side of dam.
1950	A12444-16	Flood conditions; Red River overflow present in a number of places including former Netley cut.
1963	A17982-82	No flow through cut, former cut present only as a notches in bank on Netley Lake and Red River sides.
1965 - Aug.	A18983-28	No flow through cut, former cut present only as a notches in bank on Netley Lake and Red River sides; no significant change since 1963 photo.
1968	A20400-16	No flow through cut, former cut present only as notches in bank on Netley Lake and Red River sides; no significant change since 1965 photo.
1972	A22665-135	Narrow, single channel breach apparent (Figure 2).
1977 - Jul. 12, 13	A24700-135	Narrow, single channel breach apparent, slightly wider than in 1972 photo.
1989 - Jun. 14	A27451-245	Wider, two channel breach apparent.
1989 - Jun. 15	A27453-266	Wider, two channel breach apparent.
1994	A28069-65	Wider, two channel breach apparent; no significant change since 1989 photo.

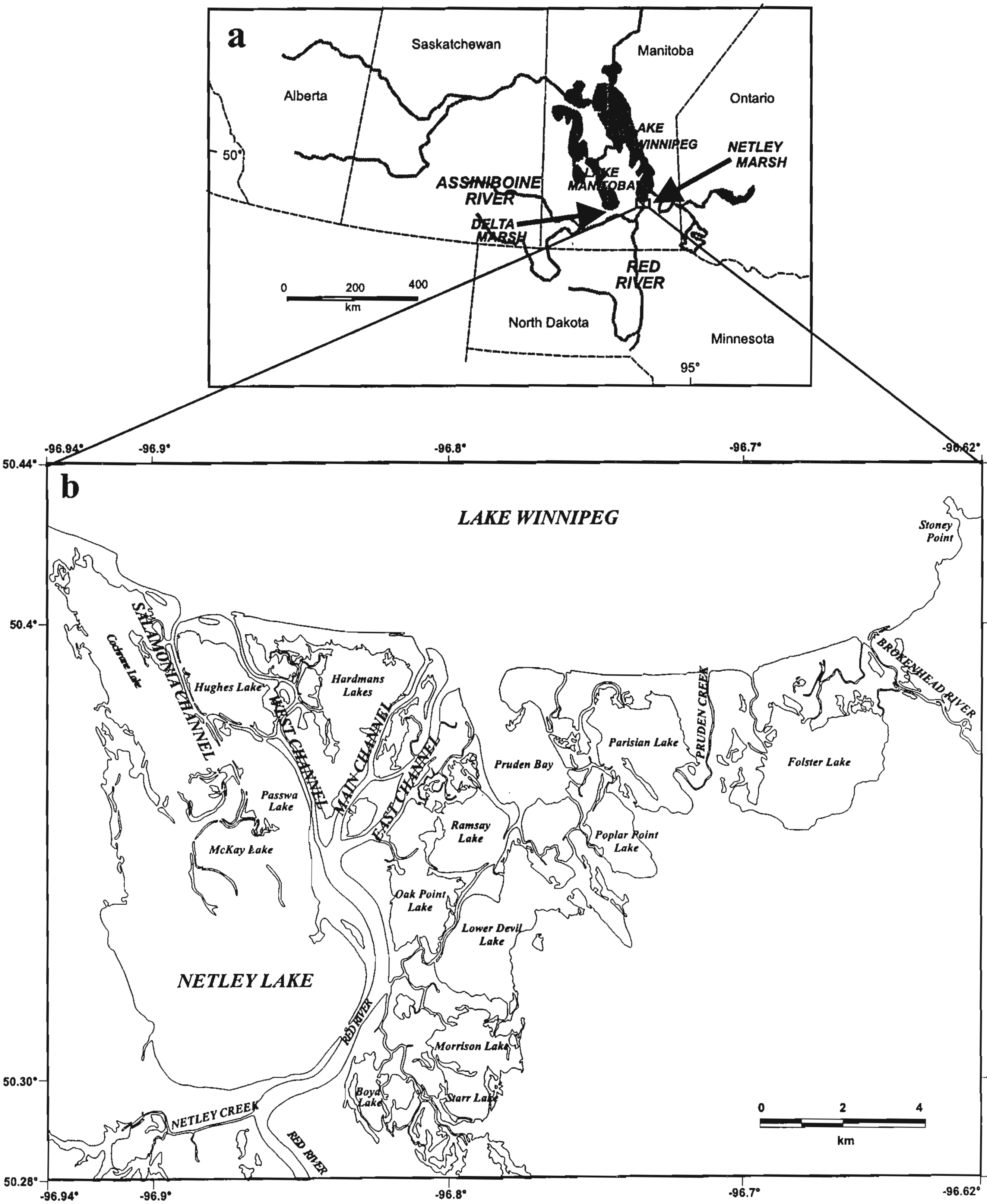

Figure 1. (a) Location of Netley Marsh and Delta Marsh at southern ends of Lake Winnipeg and Lake Manitoba, respectively, and (b) location of Netley Lake within Netley Marsh.

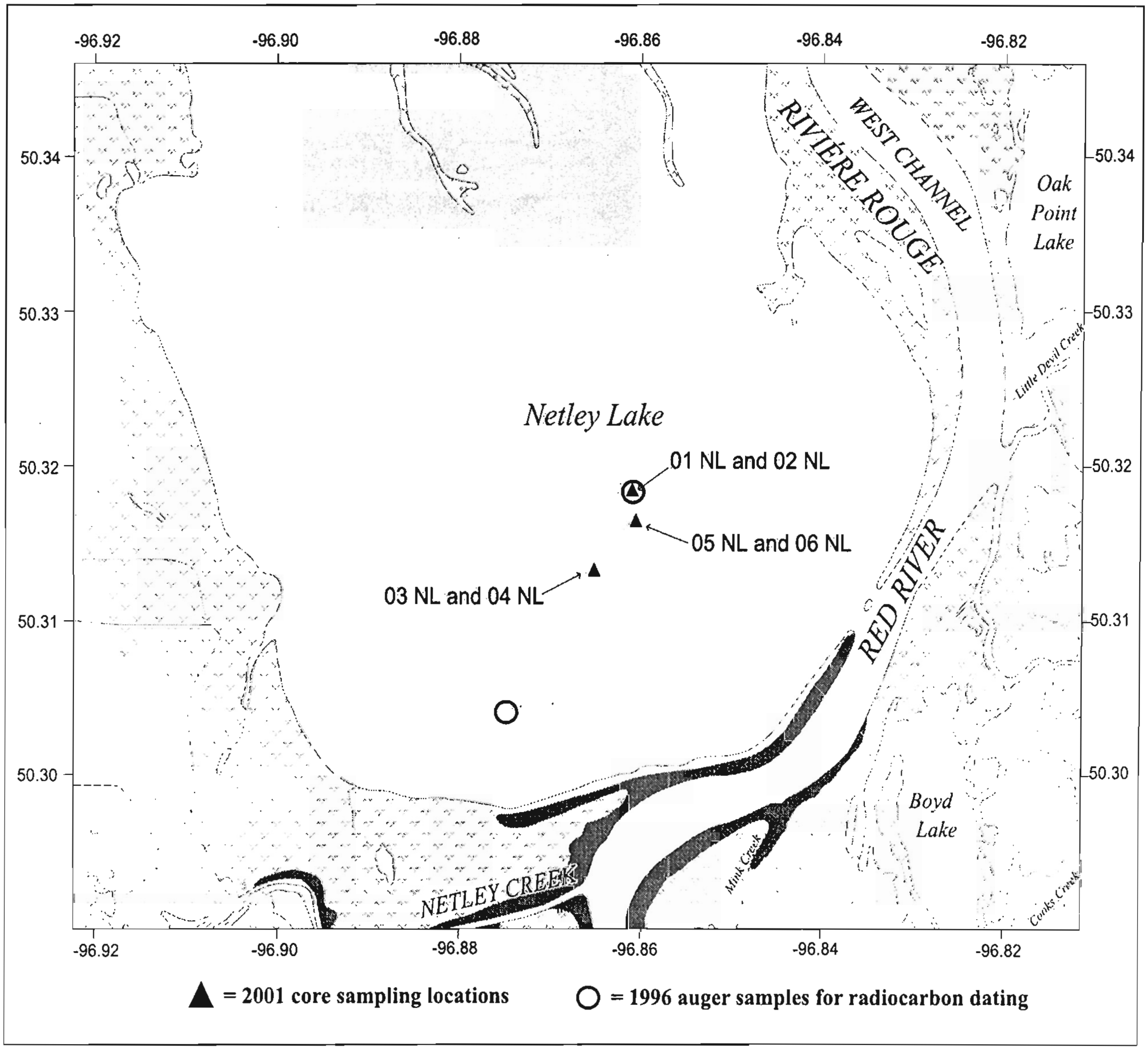

Figure 2. Location of 2001 coring sites and 1996 auger samples for radiocarbon dating in Netley Lake

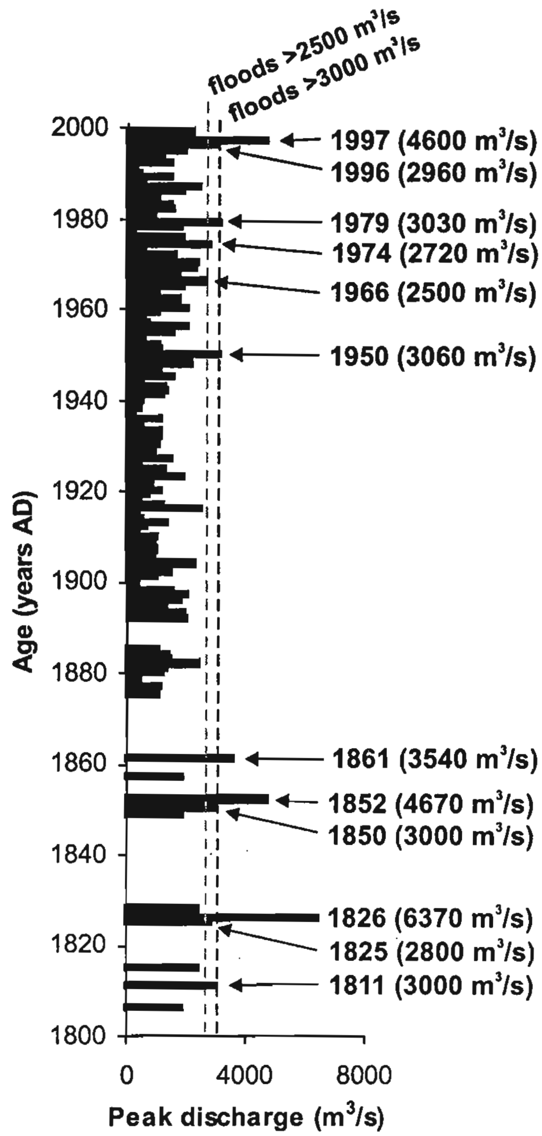

Figure 3. Peak yearly Red River discharge since 1800. Floods with peak discharge = 2500 m^3/s are indicated and discharge values given. The post-1875 record is derived from instrumental records of flood stage at Winnipeg, whereas the pre-1875 record is derived from historical records (Rannie, 1998).

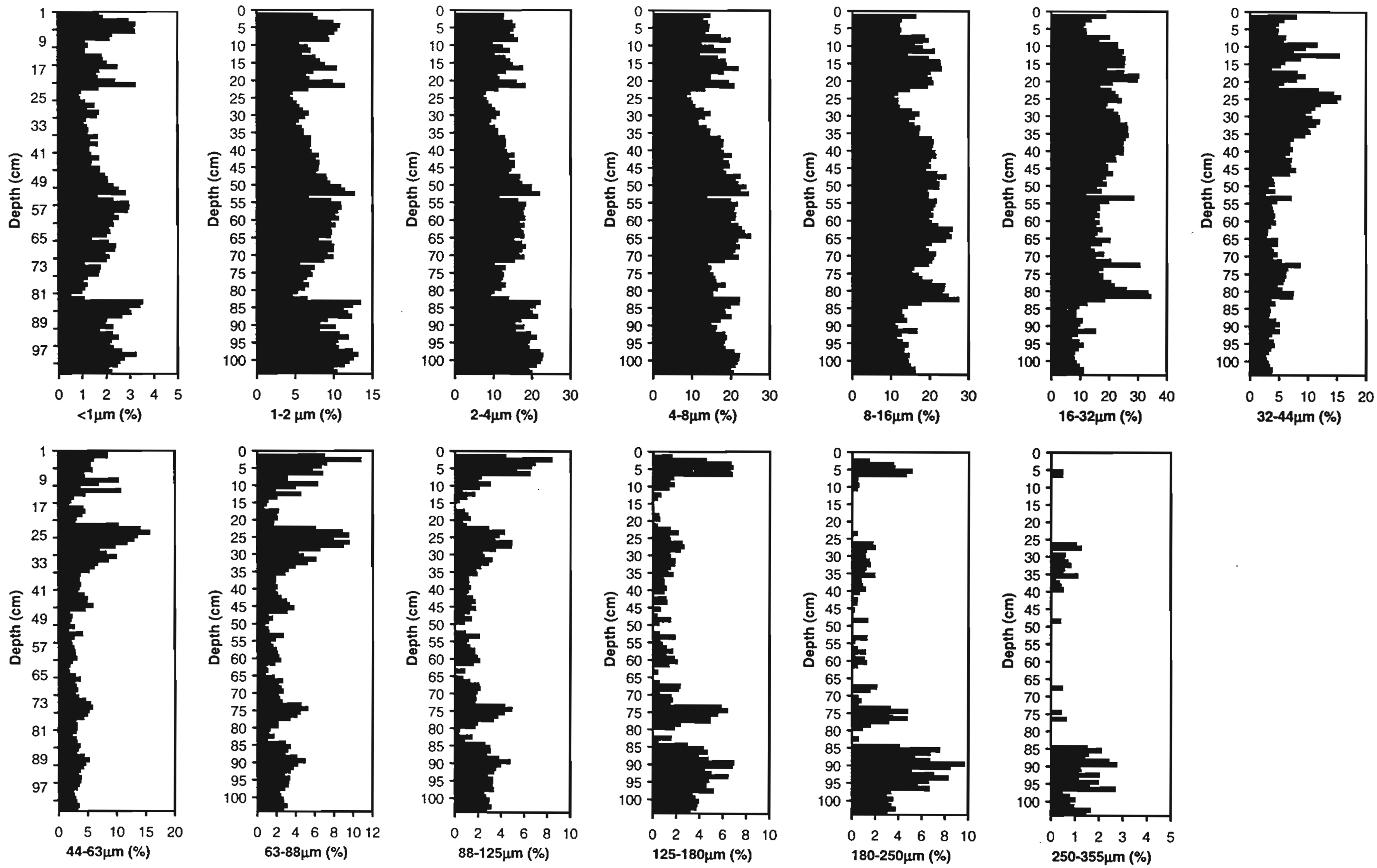

Figure 4. Down-core variationsof grain-size for selected size classes in Netley Lake core (06 NL)

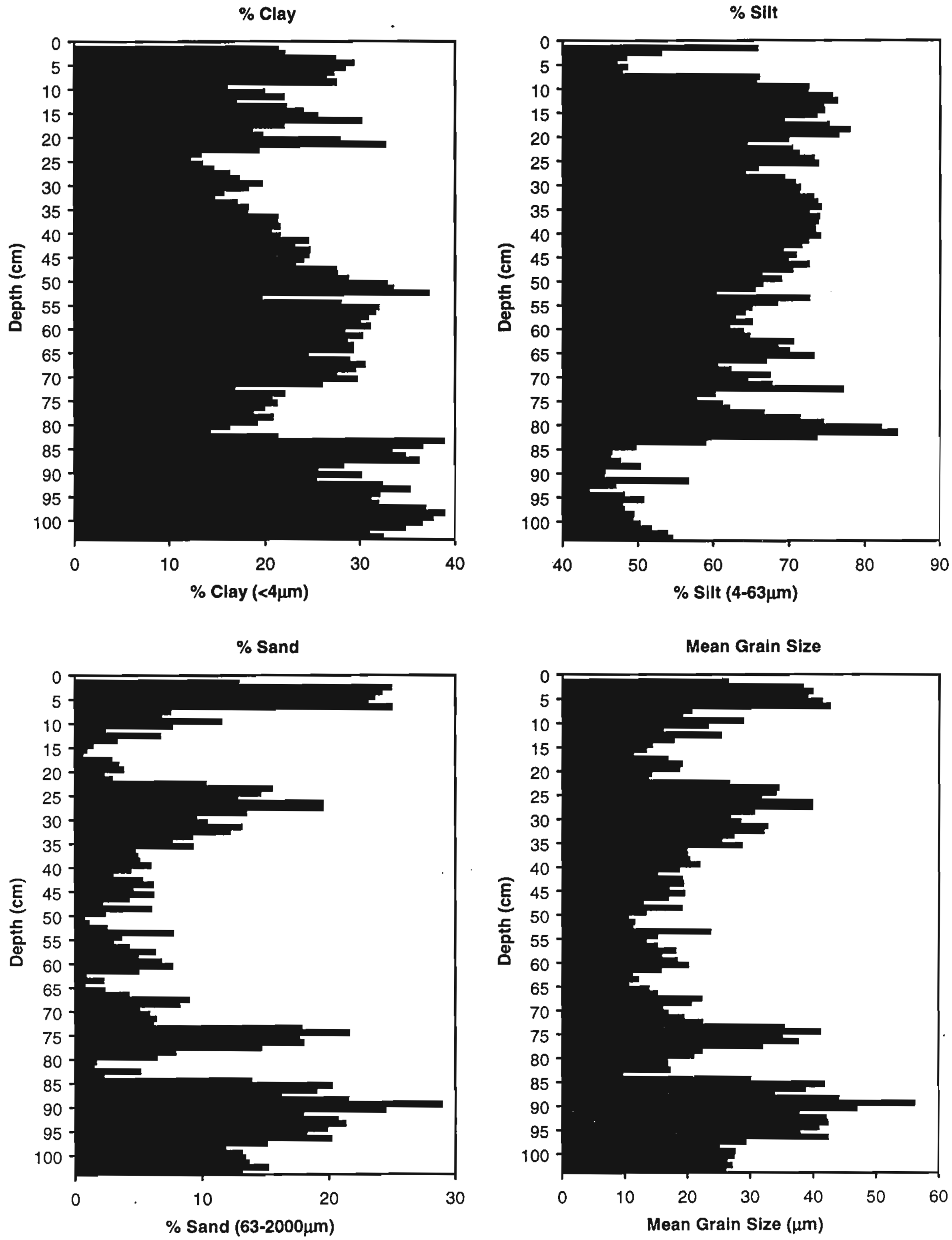

Figure 5. Down-core variations in % clay, % silt, % sand and mean grain size for Netley Lake core (06 NL). Note x-axis for silt starts at 40 %, all other graphs start at 0 %.

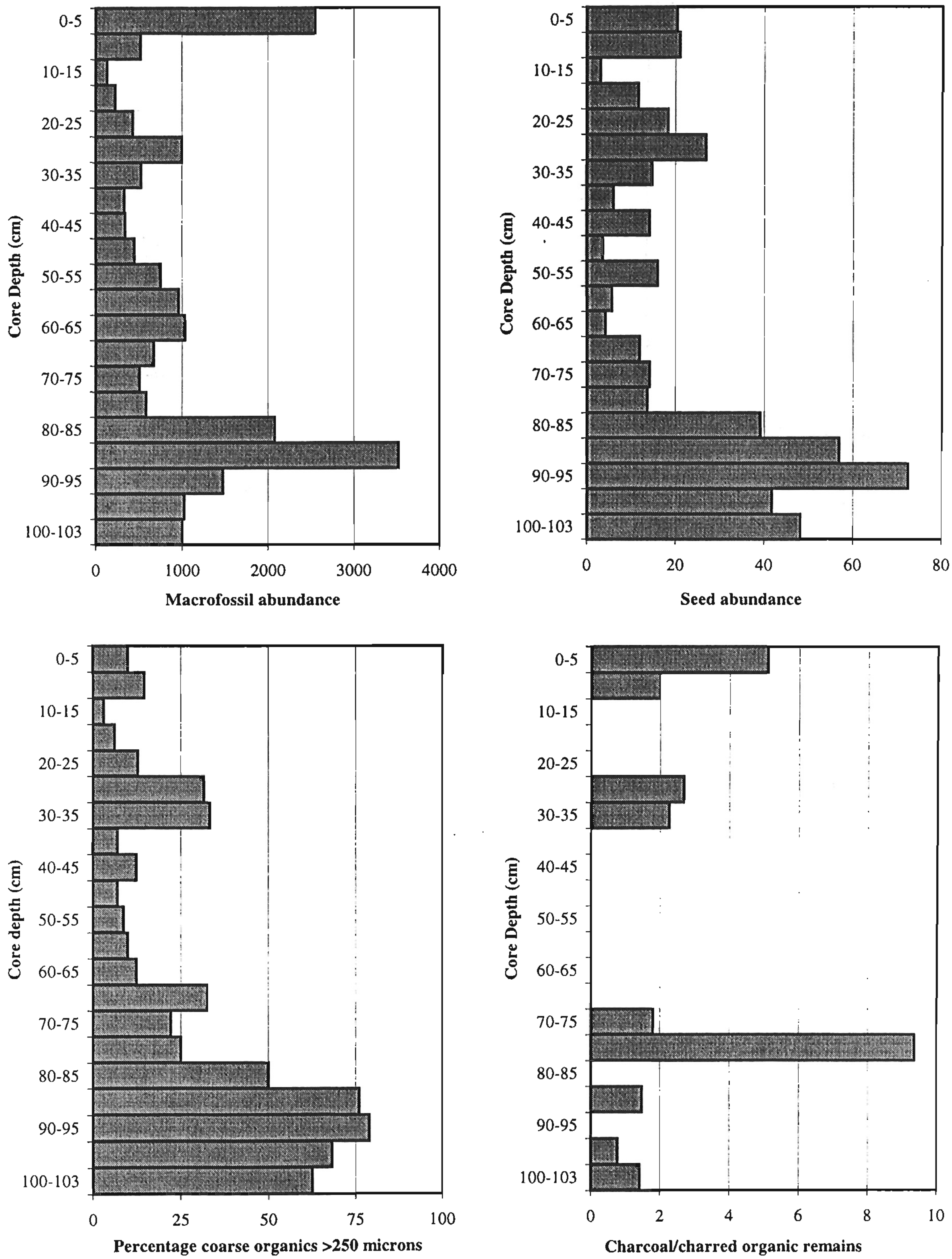

Figure 6. Down-core variations in the number of macrofossil, seed, organic matter and charcoal fragment identifications in Netley Lake core (06 NL)

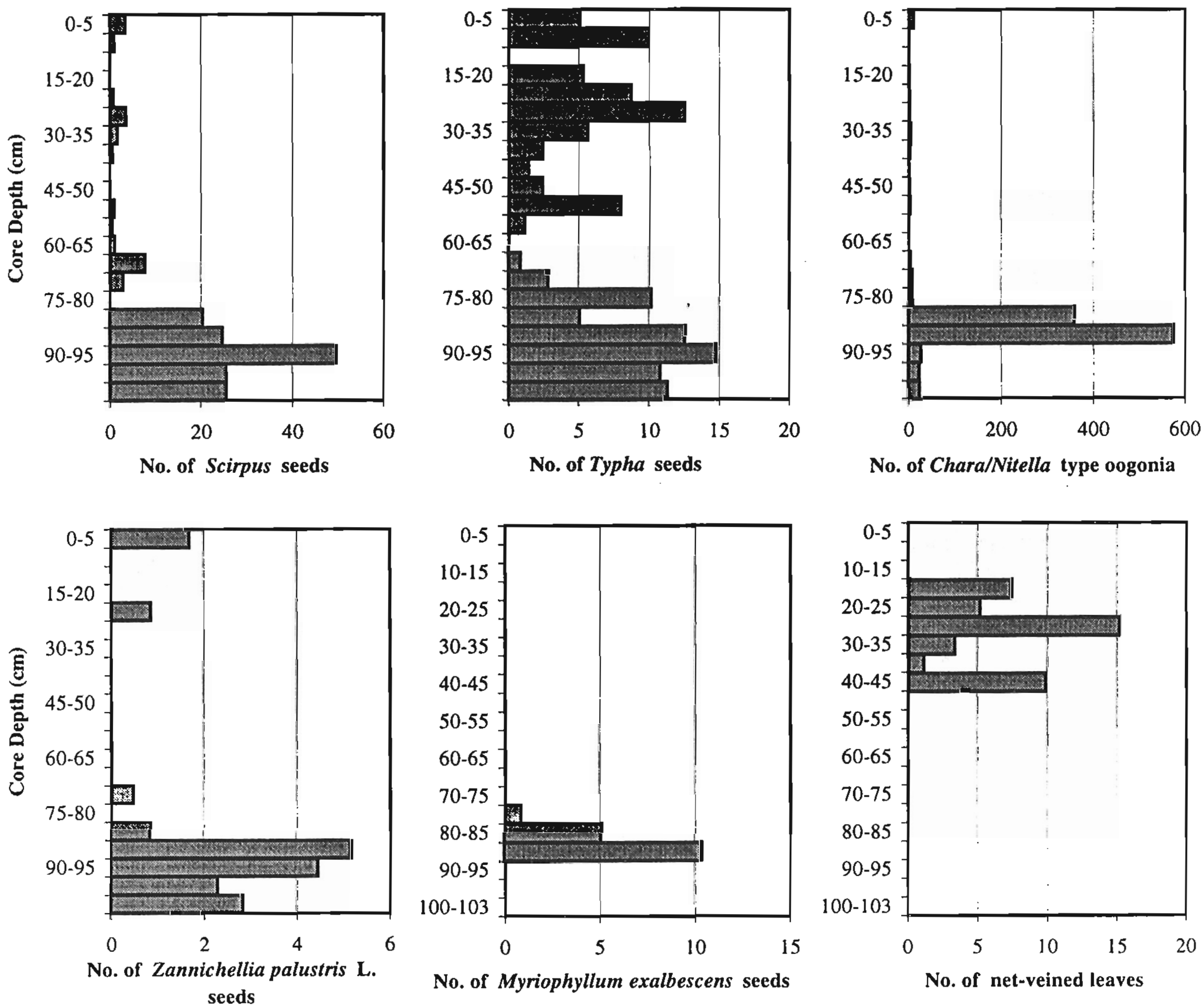

Figure 7. Down-core variations in abundance of dominant floral macrofossil taxa in Netley Lake core (06 NL)

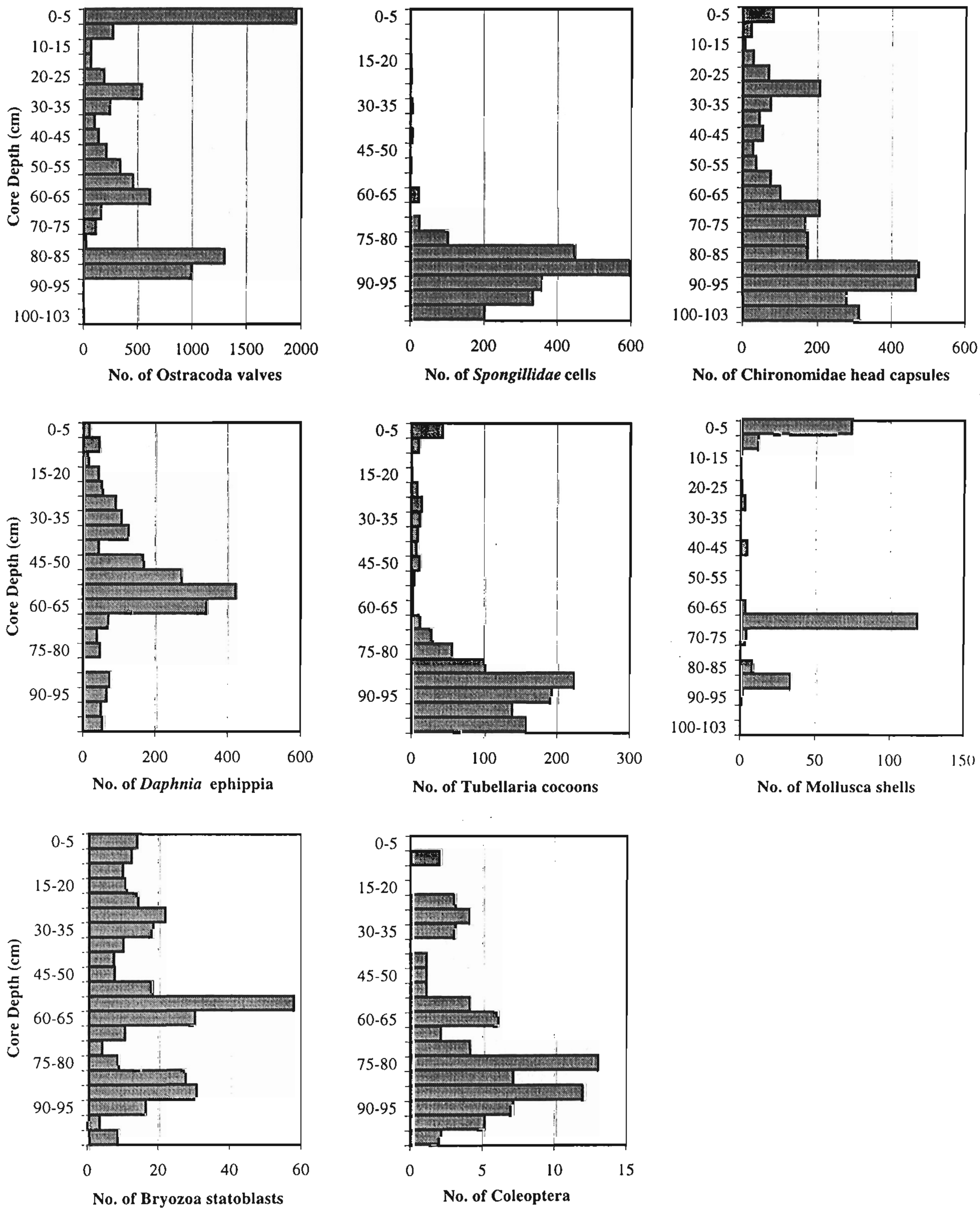

Figure 8. Down-core variations in abundance of dominant faunal macrofossil taxa in Netley Lake core (06 NL)

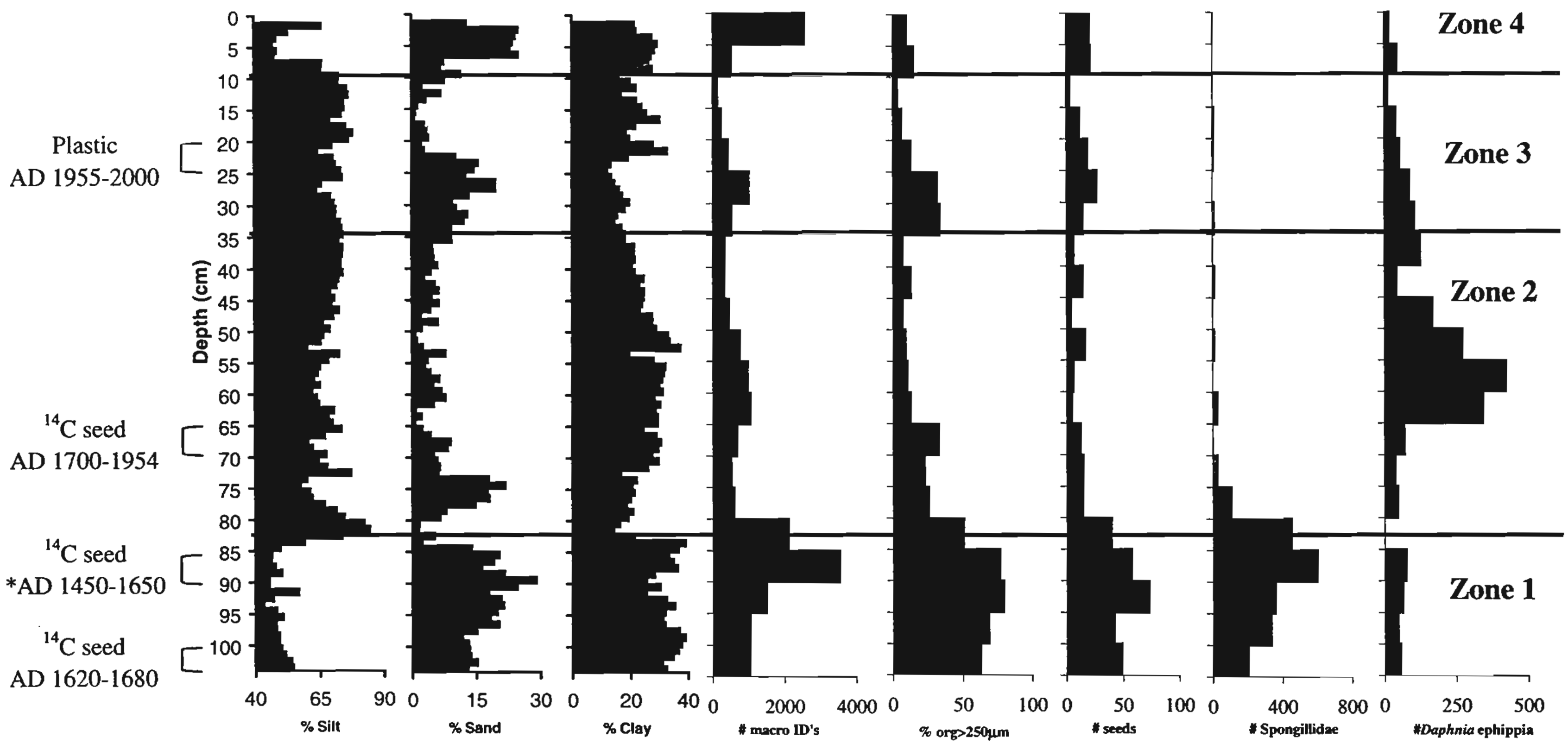

Figure 9. Down-core zonation of Netley Lake textural and macrofossil trends. * seed is believed to have been reworked.

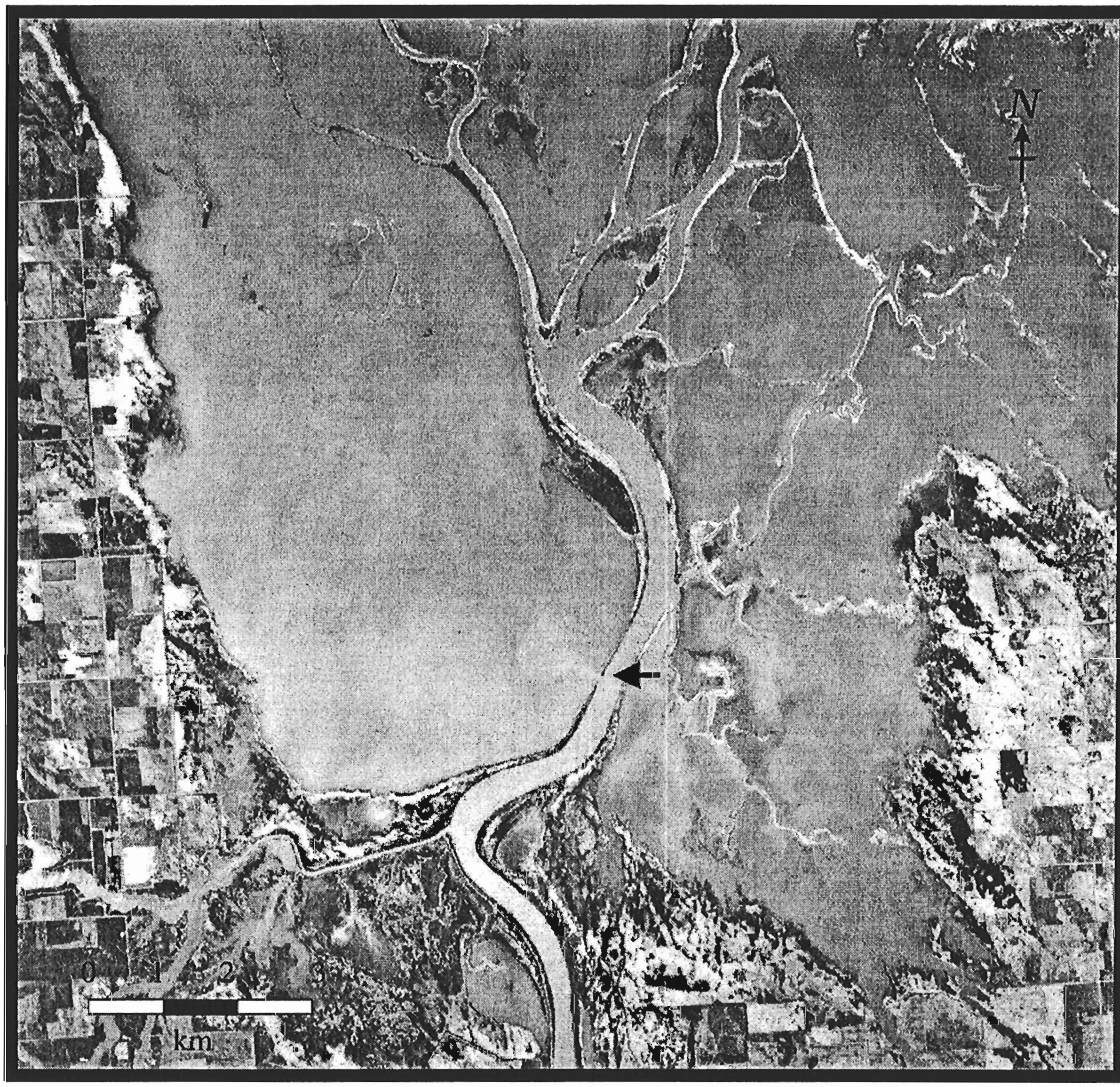

Figure 10. 1972 air photo of Netley Lake showing breach of the western levee of the Red River, indicated with arrow. National Air Photo Library A22665-135. Note the faint tonal contrast within Netley Lake interpreted as a sediment charged plume originating at the breach.