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Abstract: The physical and geochemical characteristics of three lakes in the Red River valley reveal a strong anthropogenic influence on the limnological systems. Agricultural nitrogen and phosphorus input has turned Lake Louise and Horseshoe Lake into eutrophic water bodies with brackish water and high algal production during the growing season. The consumption of oxygen results in dysoxic to anoxic lake bottoms and may account for the large quantities of organic matter preserved within the sediment. An anoxic sediment column has resulted in metal cycling and the obliteration of any flood layers deposited in the lake basins. In contrast, Salt Lake is a well oxygenated, eutrophic saline lake. Water samples reveal distinctive and different chemical signatures for each of the lakes and for the Red River; however, chemical shifts resulting from lake-basin inundation are not recorded in the lake-sediment cores.

Résumé : Les caractéristiques physiques et géochimiques de trois lacs dans la vallée de la rivière Rouge révèlent une forte influence anthropique récente sur les systèmes limnologiques. Des apports d'azote et de phosphore de sources agricoles ont transformé les lacs Louise et Horseshoe en des plans d'eau eutrophiques aux eaux saumâtres et à forte production d'algues au cours de la saison de croissance. La consommation d'oxygène fait en sorte que les fonds des lacs sont dysoxiques à anoxiques et elle pourrait être la cause des grandes quantités de matière organique préservées dans les sédiments. Une colonne sédimentaire anoxique a entraîné un recyclage des métaux et l'occultation de toute couche de dépôt d'inondation qui se serait mise en place à l'intérieur des bassins lacustres. Par opposition, le lac Salt est un lac salé eutrophique, bien oxygéné. Les échantillons d'eau révèlent des signatures chimiques caractéristiques et différentes d'un lac à l'autre et des lacs par rapport à la rivière Rouge. Toutefois, les carottes de sédiments extraites du fond des lacs ne présente pas la trace de déplacements chimiques qui résulteraient d'inondations dans les bassins lacustres.

INTRODUCTION

Following the 1997 flood disaster, the Red River Valley Flood Protection Program was created to enhance flood protection and flood management in southern Manitoba (*see* Topping and Caligiuri, 1999). As part of this program, the Geological Survey of Canada and the Manitoba Geological Survey are investigating the paleoflood history and geological controls on flooding for the Red River (Brooks et al., 1999; St. George et al., 1999). This paper deals with one particular aspect of the study, the examination of lacustrine sediments in the Red River vicinity as a proxy to reconstruct a pre–nineteenth century paleoflood record and a paleoenvironmental framework for the Red River valley.

Southern Manitoba is prone to large-scale, ice-jam flooding during the spring freshet of the Red River. In 1997, the area experienced the third largest flood event since 1826. After the floodwaters receded, a thick mud drape resulting from the flood could be found throughout the flooded Red River valley. Floodplain lakes that had experienced inundation were cored and a distinct 1.5 to 3.0 cm thick floodbed was observed. As a result of these observed flood deposits, a research plan was formulated to look for flood layers in floodplain lake cores.

Floodplain lakes are natural basins located proximal to the river and receiving river input only during large flood episodes. Riverine sediments and water chemistry are markedly different from the normal lake waters and background lacustrine sedimentation. In this paper, lithological (grain size and mineralogical), geochemical, and chronological data from lake-sediment cores from Horseshoe Lake and Lake Louise in Manitoba, and Salt Lake in North Dakota are discussed. These results are compared and contrasted with data from the Red River, and the data are assessed to determine if a flood record can be reconstructed. This information will supplement biostratigraphic work that is in progress and will be summarized in a subsequent publication. The cores represent the late Holocene history of sedimentation in all three lake basins and complement an existing pollen history from Lake Louise (Brooks and Grenier, 2001).

STUDY AREA

The Red River is a low-energy, suspended-load meandering river that migrates laterally at a relatively low rate. Reflecting this, there are only eight channel-scar and oxbow lakes between the Canada–United States border and Lake Winnipeg. Two perennial lakes, Lake Louise and Horseshoe Lake (Fig. 1), were chosen for coring. Although it is not a channel-scar lake and lies outside the hydrological floodplain of the Red River, Salt Lake in North Dakota (Fig. 1) was also chosen for coring. It is a saline lake that is subject to backflooding by fresh water when the Red River is in flood. The change in water salinities caused by periods of backflooding offered a rare opportunity to look for a geochemical flood signature.

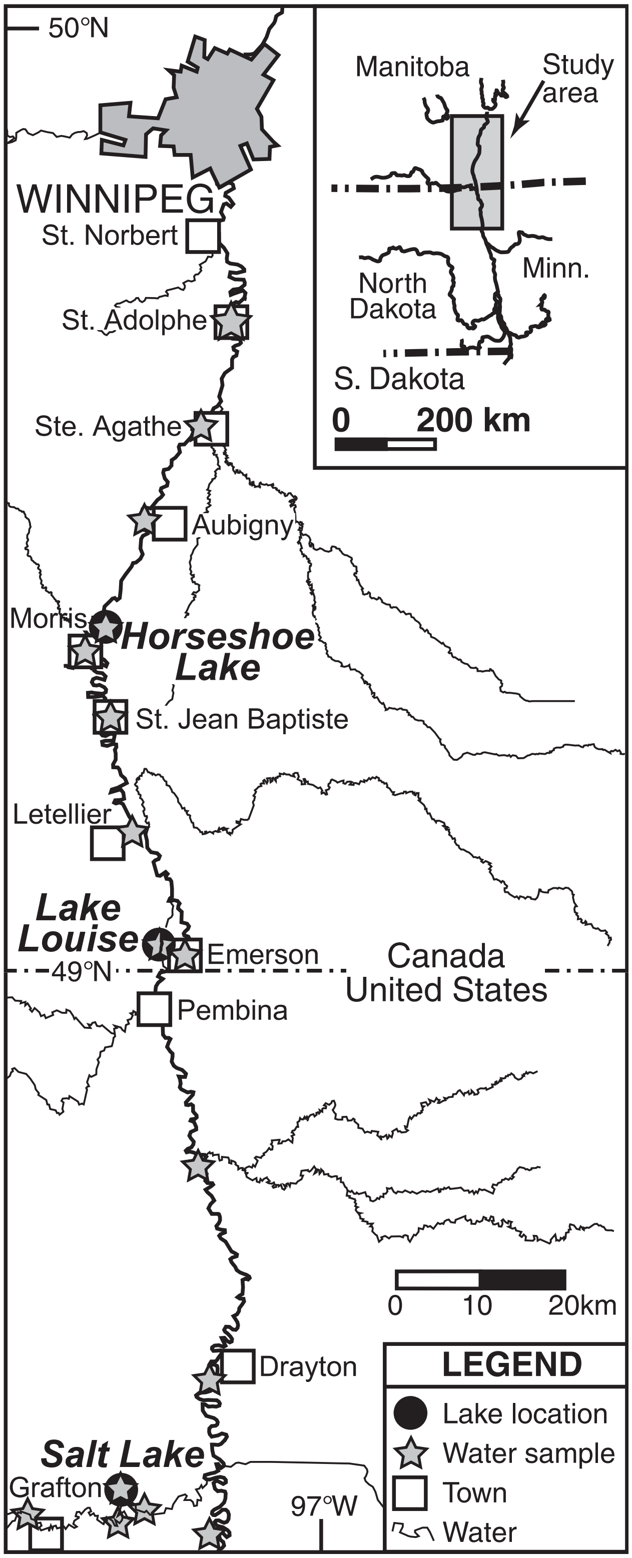

Figure 1. *Locations of Horseshoe Lake, Lake Louise, and Salt Lake, and water samples taken within the Red River valley.*

Lake Louise is located near Emerson, Manitoba, about 2.5 km north of the Canada–United States border and 2 km west of the Red River (Fig. 1). The lake is elongated and only slightly sinuous in shape. It is up to 175 m wide, 2050 m long, and 2.4 m deep. It is bordered by a thin stretch of woodland on its eastern and northern ends. To the south and west, the lake is surrounded by farmland.

Horseshoe Lake is a perennial oxbow lake located 2.5 km southeast of Morris, Manitoba and 1 km east of the Red River (Fig. 1). The lake is 1250 m long, up to 150 m wide, and about 2.0 m deep. On the floodplain (i.e. within the crescent of the oxbow), there is a deciduous woodland, whereas the outside of the lake is surrounded by farmland.

Salt Lake is a small, saline prairie lake located 10 km east-northeast of Grafton, North Dakota and 10 km west of the Red River (Fig. 1). This lake is oval in shape (1600 m long and 500 m wide) and is spring fed. The lake was 0.69 m deep at the time of coring. The salinity of the lake probably originates from groundwater. The lake has a single outflow channel that feeds into the Park River, which then flows into the Red River. Salt Lake is surrounded by farmland.

METHODS

In May 1998, two water samples were taken from both Lake Louise and Horseshoe Lake, and five samples were taken along the Red River (at bridge crossings near the towns of Ste. Agathe, Aubigny, Morris, Letellier, and Emerson). Conductivity and pH measurements were taken on each sample at the time of collection (Table 1). Samples were acidified with sulphuric acid and later analyzed by Dionex® ion chromatography for nitrite, nitrate, fluorine, phosphate, bromine, sulphate, and chlorine at the Analytical Chemistry Laboratory of the Geological Survey of Canada in Ottawa. Minor elements were determined by ICP-MS (also at the GSC-Ottawa). In June 1999, sixteen water samples were collected from similar locations throughout the Red River valley. Samples collected for total phosphorus (TP) determination were analyzed by the Regional Municipality of Ottawa-Carleton (Table 1).

Livingstone cores were taken from the frozen lake surface of Salt Lake on March 1, 2000, and from Horseshoe Lake and Lake Louise on March 2, 2000 (Livingstone, 1955). At Salt Lake, a total of 124 cm of core was retrieved. An 84 cm long core was extracted from Horseshoe Lake, whereas only 37 cm of core were retrieved from Lake Louise. Cores were kept refrigerated at 4°C until June 2000, when they were subsampled, freeze dried, and analyzed for geochemistry (total metal and ion), Rock-Eval®, grain size, mineralogy, and geochronology. Organic matter concentrations were measured by loss-on-ignition. Detailed descriptions of all coring and analytical methodologies were presented by Medioli (2001).

Lake Louise and Horseshoe Lake cores were subsampled at 0.5 cm intervals for inorganic geochemistry and Rock-Eval®, whereas the Salt Lake core was sampled at 1 cm intervals. Grain size and mineralogy were sampled at 5 cm

Table 1. Measured total phosphorus (TP) values for water samples from the Red River valley.

Date collected	Sample location	Total P (mg/L)	Conductivity (mS/cm)	pH
Lake samples:				
June 17, 1997	Horseshoe Lake	n/a	0.77	6.96
June 17, 1997	Lake Louise	n/a	0.59	6.54
May 24, 1998	Horseshoe Lake	0.109	1.03	8.81
May 24, 1998	Horseshoe Lake	0.129	1.09	8.85
May 24, 1998	Lake Louise	0.111	0.95	8.59
May 24, 1998	Lake Louise	0.091	0.95	8.55
June 28, 1999	Horseshoe Lake	0.250	2.00	n/a
June 28, 1999	Lake Louise	0.081	0.64	n/a
River samples:				
May 24, 1998	Red River at Emerson	0.500	0.46	7.85
May 24, 1998	Red River at Letellier	0.400	0.47	7.85
May 24, 1998	Red River at Morris	0.500	0.48	7.92
May 24, 1998	Red River at Aubigny	0.400	0.46	7.90
May 24, 1998	Red River at Ste. Agathe	0.600	0.46	7.87
June 26, 1999	Park River, west of Grafton, ND	0.190	0.96	7.00
June 26, 1999	Park River, north of Oakwood, ND	0.250	0.87	6.93
June 26, 1999	Field near Salt Lake, ND	0.320	7.25	6.27
June 26, 1999	Stream exiting Salt Lake, ND	0.560	6.80	5.27
June 26, 1999	Red River at Interstate 29, ND	0.370	0.57	6.28
June 26, 1999	Red River at Drayton, ND	0.300	0.55	6.20
June 26, 1999	Red River at Hwy. 5, ND	0.420	0.56	6.01
June 27, 1999	Red River at Ste. Adolphe	0.250	0.60	n/a
June 27, 1999	Red River at Ste. Agathe	0.280	0.57	n/a
June 27, 1999	Red River at Aubigny	0.390	0.57	n/a
June 27, 1999	Red River at Morris	0.320	0.55	n/a
June 27, 1999	Red River at St. Jean-Baptiste	0.310	0.55	n/a
June 27, 1999	Red River at Letellier	0.410	0.57	n/a
June 27, 1999	Red River at Emerson	0.390	0.55	n/a

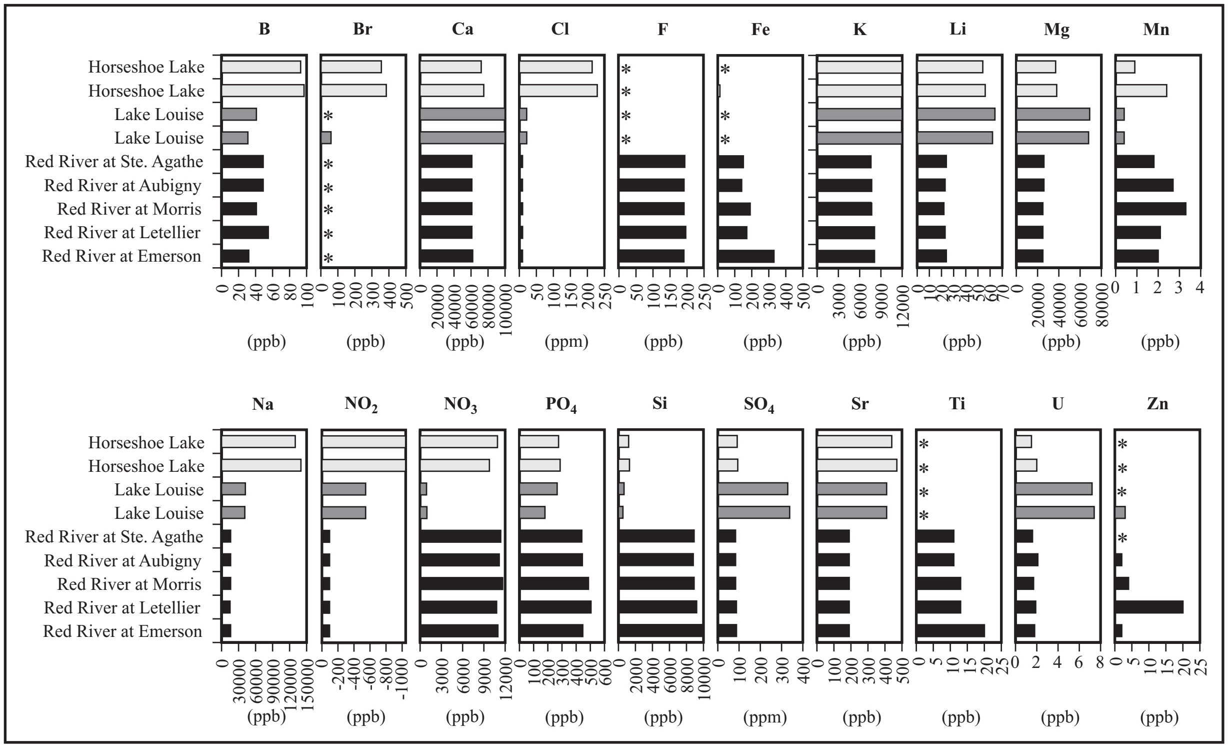

Figure 2. *Aqueous geochemical data from Horseshoe Lake, Lake Louise, and various locations along the Red River. Only those elements showing significant differences between lacustrine and riverine waters are shown. Asterisks indicate values below the limit of instrumental detection.*

intervals for the Horseshoe Lake core, whereas samples were taken at 2.5 cm intervals for the Lake Louise core. The Salt Lake core was not analyzed for grain size or mineralogy due to a lack of sufficient sample volume.

RESULTS AND INTERPRETATION

Water geochemistry

Total phosphorus (TP) values were measured for water samples from Lake Louise, Horseshoe Lake, and the Red River. As shown in Table 1, water samples have very high concentrations of phosphorus (i.e. >0.1 mg/L) and, according to Wetzel (1983), are considered hypereutrophic. The Red River water samples, however, are between two and six times more enriched in phosphorus than the lake waters.

Water samples from Lake Louise and Horseshoe Lake have dramatically different chemical compositions compared to samples collected from the Red River (Fig. 2). These lakes contain significantly higher concentrations of bromine, potassium, lithium, sodium, nitrite, and strontium than the Red River waters. In contrast, they contain less fluorine, manganese, phosphate, silica, and titanium compared to Red River waters. These chemical concentrations partly explain the higher conductivity values shown in Table 1 for Horseshoe Lake and Lake Louise, relative to Red River waters. The conductivity (a proxy for salinity) measured for Salt Lake is more than an order of magnitude higher than that of the Red River and reflects a very different aqueous environment and water source. Figure 2 shows 20 chemical species for each of the 1998 samples (no samples were collected from Salt Lake).

Furthermore, the aqueous geochemistry reveals that Horseshoe Lake is brackish (very high concentrations of chlorine, sodium, and boron), whereas Lake Louise is more alkaline (higher calcium and magnesium concentrations) than either Horseshoe Lake or the Red River. Both lakes are depleted in silica with respect to the Red River. This may account for silica dissolution observed in diatom samples from Lake Louise (Prévost and Brooks, 2000). Horseshoe Lake appears to receive more agricultural nitrogen input than Lake Louise (high nitrite and nitrate values).

Sedimentology

Lake Louise sediment is composed of massive black mud with no visible sedimentary structures. Rootlets and shell fragments are disseminated throughout the core (Fig. 3). The cores emitted a strong sulphurous smell (H_2S gas indicative of anoxic depositional-diagenetic environment) upon extraction and subsampling. The sediment comprises 60 to 70% silt, 30 to 40% clay, and less than 2% sand. A marginal fining upcore was observed. Clay minerals make up 50 to 60% of the mineralogy. Abundant quartz (10–14%) and plagioclase (0–13%) are also present. Potassium feldspar and dolomite

Lake Louise, Manitoba

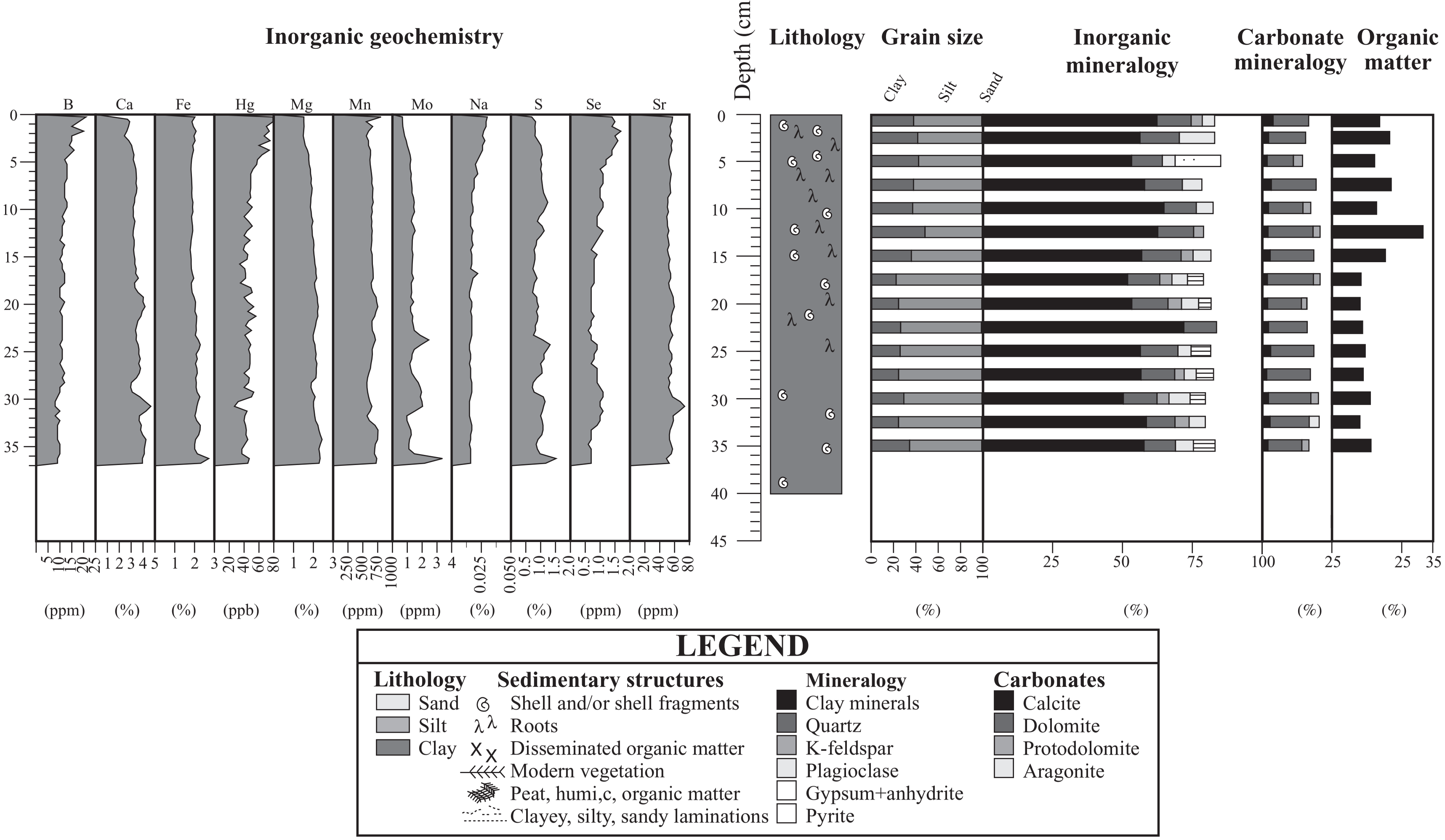

Figure 3. *Sedimentology, grain size, mineralogy, and inorganic geochemistry of Lake Louise sediments.*

occur throughout the deposits, whereas organic matter decreases (from 32 to 10%) downcore. One gypsum peak occurs at 5 cm and pyrite increases downcore.

The massive black mud of Horseshoe Lake contains disseminated organic debris, roots, and shells (Fig. 4). The top 20 cm of sediment emitted a strong sulphurous (H_2S) odour. The sediment is predominantly composed of 55 to 65% clay, about 35% silt, and less than 3% sand. Core mineralogy is dominated by clay minerals, with 5 to 7% quartz, 0 to 5% potassium feldspar, and 0 to 7% plagioclase. The organic matter is about 15% of the sediment by weight. Calcite increases to 10% below a depth of 28 cm. Gypsum and anhydrite occur at depths of 5 and 60 cm, and pyrite occurs at 10 and 55 cm (Fig. 4).

The Salt Lake sediment consists of massively bedded mud and silt with occasional, very thin, sandy laminae (Fig. 5). It produced a strong sulphurous smell upon extrusion from the core barrel. The deposits contain an abundance of randomly scattered grass and plant debris. Shell fragments occur occasionally in the core. No grain size or mineralogical data are available from Salt Lake.

Inorganic sediment geochemistry

Inorganic geochemical analysis of Lake Louise sediments reveals no significant fluctuations in downcore elemental values (Fig. 3). Iron values are very constant throughout the core. A slight increase in manganese in the top 4 cm of sediment is accompanied by a decrease in sulphur. The top 4 cm also show an enrichment in mercury. Similar enrichments are seen in lead, zinc, copper, cadmium, and antimony (not plotted). Zones of increased metal concentration are also observed at depths of 20 to 21 cm and 28 to 29 cm.

Similarly, no consistent major elemental fluctuations are observed in the Horseshoe Lake sediments (Fig. 4). As in the Lake Louise core, metals (copper, lead, zinc, nickel, cobalt, chromium, barium, and gallium, all of which are mobile metals and were not plotted) are concentrated in the top 10 cm of the core, whereas sulphur, strontium, molybdenum, manganese, and calcium are depleted. Manganese depletion occurs at the top of the core and corresponds to a similar depletion in sulphur. Mercury appears to be slightly enriched in the top 28 cm of the core.

The upper 75 cm of the Salt Lake core show only very small geochemical fluctuations (Fig. 5). In contrast, there are peaks in cadmium, cobalt, arsenic, iron, nickel, and sulphur (not all of which plotted) between 75 and 80 cm in depth. The lake and its sediments are well oxygenated, as is clear from the iron, manganese, and sulphur profiles. A sharp drop in sulphur occurs at a depth of 80 cm and corresponds to a similar drop in arsenic. Salinity (Na) decreases slightly downcore. Some large-scale fluctuations are observed in the calcium profile. A major drop in molybdenum occurs between 90 and 107 cm in depth, and two mercury peaks occur at 40 and 50 cm.

Rock-Eval®

Rock-Eval® pyrolysis is used to determine the source of organic matter within sediments (Espitalié et al., 1977). All of the samples from Lake Louise, Horseshoe Lake, and Salt Lake plot as Type III (terrestrial) organic matter (Fig. 6). The Lake Louise and Horseshoe Lake samples have high total organic carbon (TOC) values, ranging from 2 to 6% and from 2 to 5%, respectively. Lacustrine sediments frequently have much lower TOC values, similar to those of the Salt Lake samples (0–2%).

Chronology

Sediment samples from each of the three lakes were submitted to Flett Analytical for ^{210}Pb analysis. Unfortunately, the margin of error on the calculated dates is high because the samples contain very low background ^{210}Pb (*see* Medioli, 2001). The low lead values made constant rate of supply (CRS) modelling (Appleby and Oldfield, 1978) very difficult for Horseshoe Lake and impossible for Lake Louise and Salt Lake. Nevertheless, based on this modelling, the top 40 cm of Horseshoe Lake sediment are equivalent to 124 years of sedimentation, giving an average sedimentation rate of 3.2 mm/year.

Due to a lack of datable material, only two macrofossil samples were submitted for accelerator mass spectrometry (AMS) dating. At Horseshoe Lake, a macrofossil sample from a depth of 84 cm produced a date of 780 ± 50 BP (Beta-151988) or 740 to 670 cal BP (calibrated to calendar years; Talma and Vogel, 1993; Stuiver et al., 1998). Grassy material, from a depth of 27 cm in Salt Lake sediments, yielded a modern radiocarbon age.

DISCUSSION

The tops of Lake Louise and Horseshoe Lake cores, retrieved shortly after the 1997 flood, contained distinct layers of light grey sediment (Fig. 7). These layers were deposited by the sediment-laden waters of the Red River as it inundated the lake basins and deposited suspended sediment. The layers ranged in thickness from 1.5 to 3.0 cm and were easily distinguished from the underlying black mud. The reason for the difference in thickness between the lakes may be twofold: 1) Horseshoe Lake is located closer to the Red River channel and was inundated longer than Lake Louise, thus receiving a greater amount of sediment; or 2) the elevated salinity of Horseshoe Lake waters, at least during initial inundation, caused the flocculation and precipitation of suspended and colloidal mineral species and clay particles (Sholkovitz, 1976; Eckert and Sholkovitz, 1976).

When the lakes were resampled a year later, the floodbeds were no longer distinguishable from the rest of the sediment package. This indicates that, when Red River waters inundate the lake basins, they bring a temporary influx of oxygenated waters that reach the sediment-water interface. How long this oxygenated period lasts is not known, but based on the

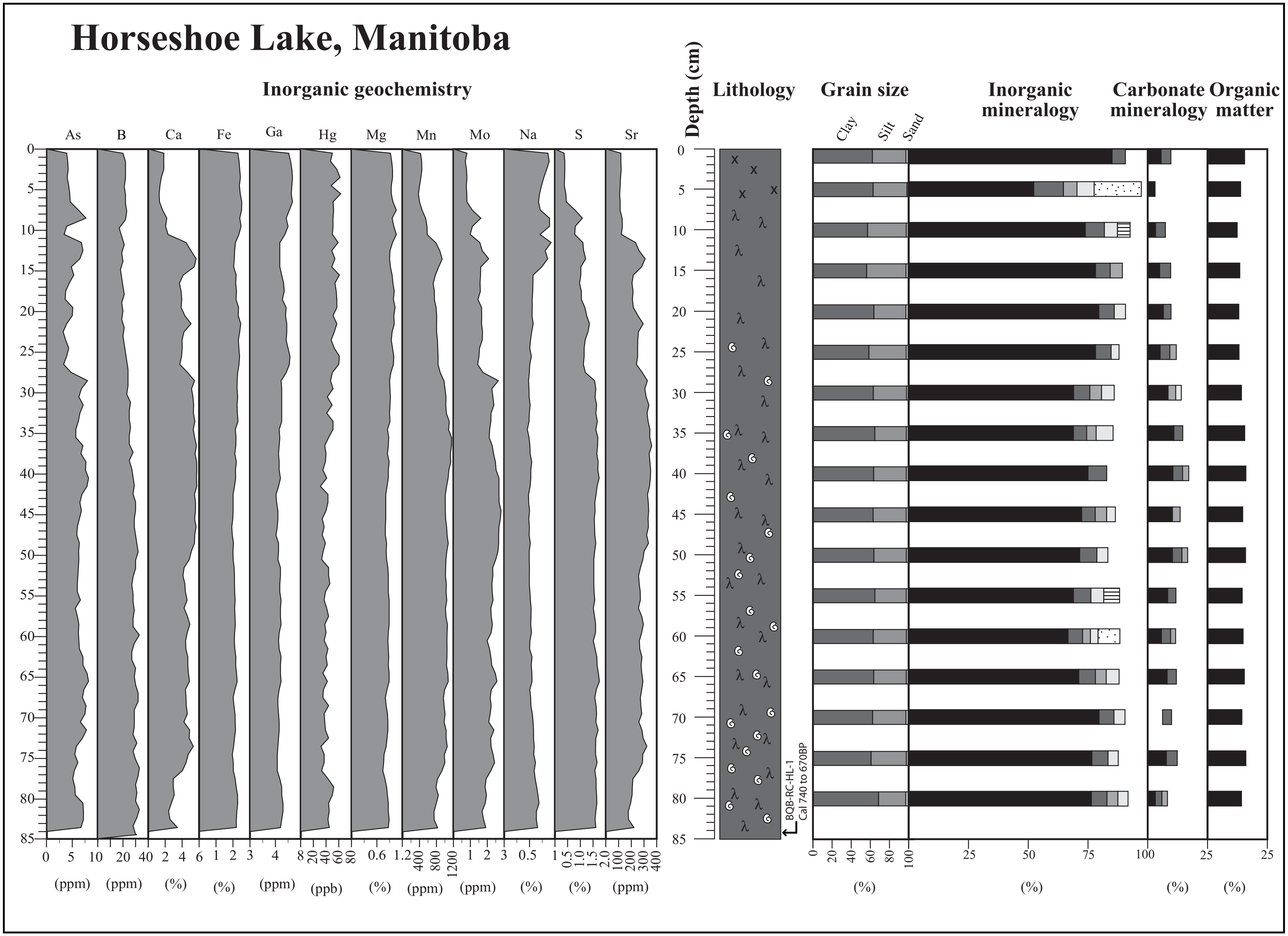

Figure 4. Sedimentology, grain size, mineralogy, and inorganic geochemistry of Horseshoe Lake sediments (see *Fig. 3 for legend).*

extensive algal growth observed in late summer, it is unlikely to have lasted beyond midsummer. There is no evidence of bioturbation within the sediments.

The high TP values of the lake and river waters reflect the effects of fertilizer runoff due to flooding within the Red River drainage basin (Freedman, 1995). In the Red River valley, phosphorus is usually applied in the spring, at the same time as seeding. In flood years, phosphorus is leached from soil and carried into the surrounding lakes, streams, and rivers. High concentrations of sodium and phosphorus in the uppermost lake sediments also reflect this anthropogenic source. The TP values increase as tributaries merge and flow into the Red River (e.g. the Salt Lake outlet flows into the Park River, which in turn flows into the Red River; *see* Table 1).

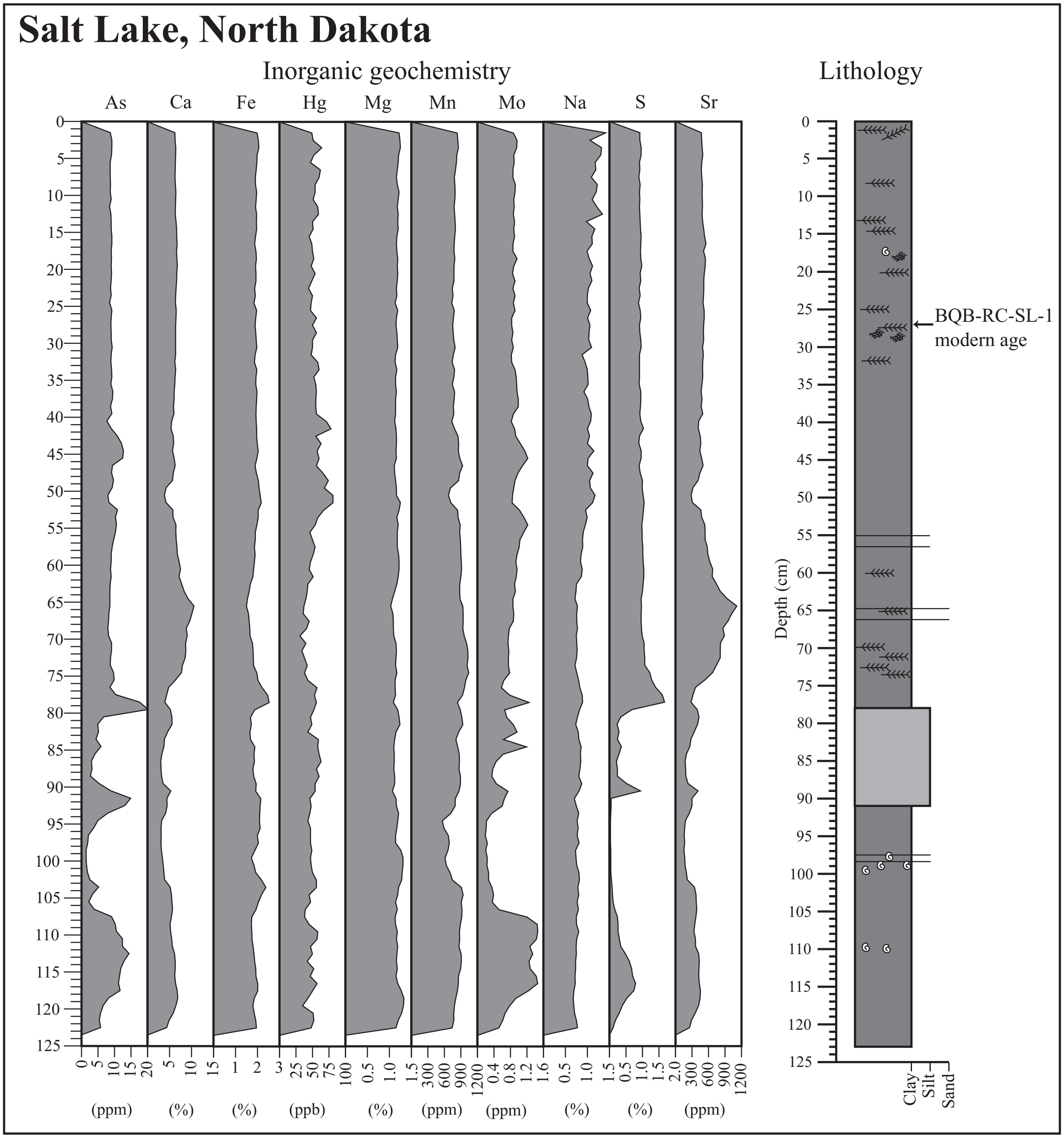

Figure 5. *Sedimentology and inorganic geochemistry of Salt Lake sediments (*see *Fig. 3 for legend).*

Water TP values of between 0.810 and 0.600 (Table 1) reveal that Lake Louise, Horseshoe Lake, and especially the Red River are hypereutrophic water bodies (Wetzel, 1983), at least in late spring–early summer. Both lakes have been observed to support an abundant algal growth throughout the summer months, which suggests that eutrophy extends throughout the growing season. Large volumes of algae in the phosphorus-rich, eutrophic waters consume water-column oxygen and create an oxygen gradient between the surface and the sediment-water interface (Freedman, 1995). The sediment column becomes anoxic, resulting in the preservation of organic matter.

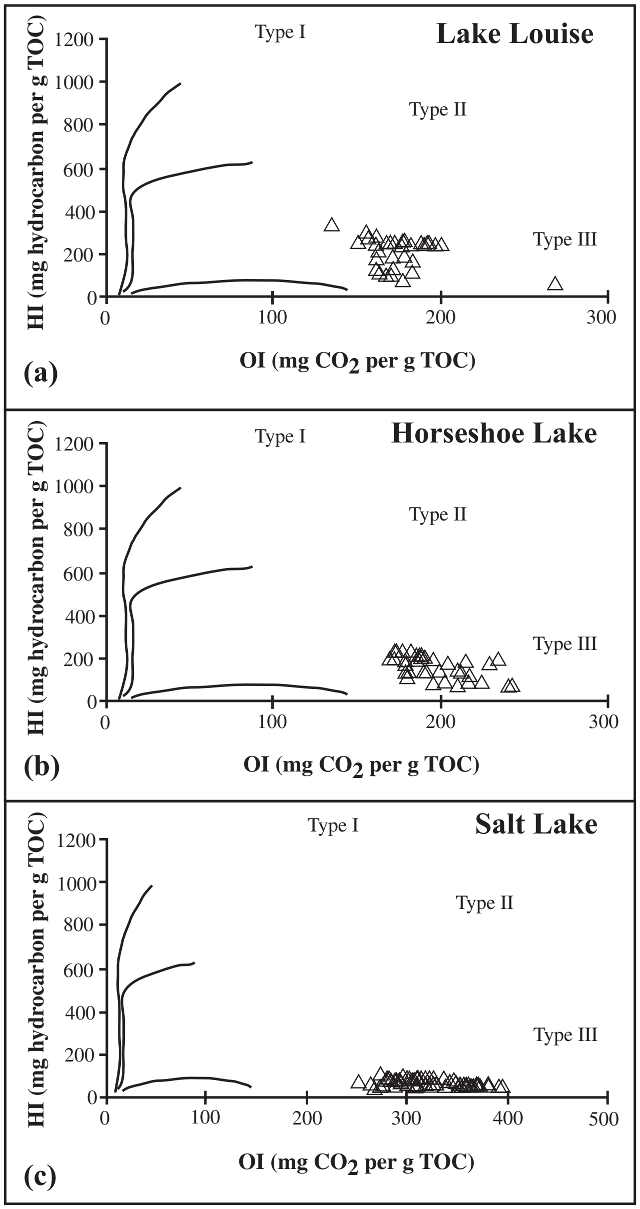

Figure 6. *Hydrogen index (HI) vs. oxygen index (OI) plots of Lake Louise, Horseshoe Lake, and Salt Lake sediments are indicative of the source of organic matter. Abbreviation: TOC, total organic carbon.*

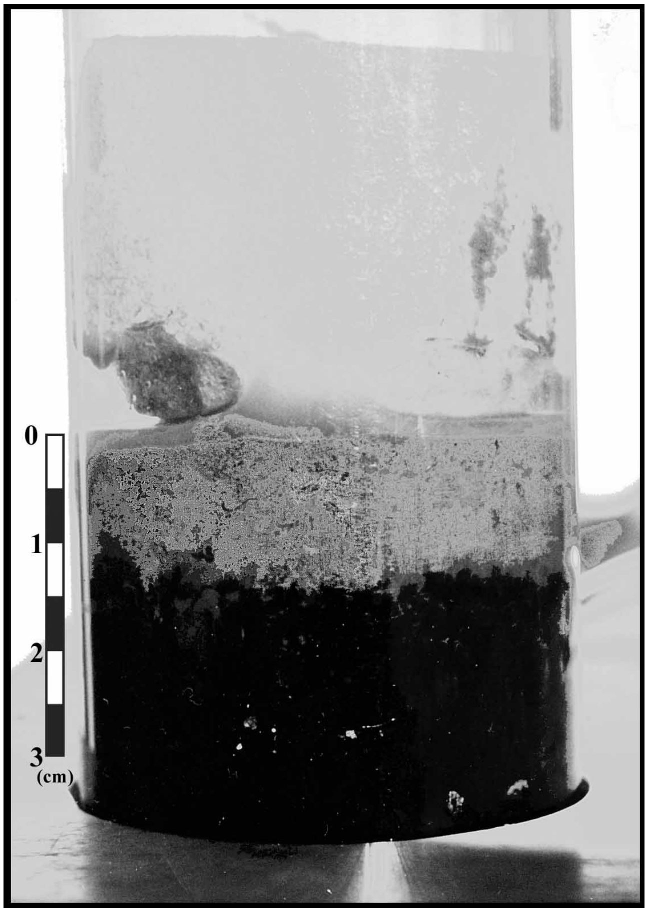

Figure 7. *Top of a short gravity core, collected in June 1997 from Lake Louise, Manitoba. Note that the 1.5 cm thick, dark gray bed, deposited on the lake bottom during the 1997 flood is visually distinct from the underlying, black, uniform sediment.*

The occurrence of high TOC values may have favoured the consumption of oxygen and led to anoxia at the sediment-water interface in both Lake Louise and Horseshoe Lake (*see* Medioli, 2001, Appendix 4). Furthermore, the abundance of pyrite in the Lake Louise core is indicative of anoxic sediment conditions at the time of pyrite precipitation (Huerta-Diaz et al., 1993), although oxic conditions may have subsequently prevailed. Sediment recovered from the bottom of the lakes is typically black in colour and emits a strong sulphurous odour, which further supports the idea of an anoxic sediment column. The manganese (and, to some degree, the sulphur) depletions at the top of the sediment columns also reflect these conditions (Tipping et al., 1984; Sundby and Silverberg, 1995; Lienemann et al., 1997; Fortin et al., 2000). Low calcium, magnesium, and molybdenum values also occur in this zone and may reflect a lower pH within the reducing sediments.

Metal cycling is a common phenomenon within anoxic lake sediments (Carignan and Tessier, 1985; Carignan and Lean, 1991; Viollier et al., 1997). The inorganic geochemical profiles from Lake Louise and Horseshoe Lake suggest that diagenetic metal cycling (specifically nickel, mercury, sodium, copper, lead, zinc, gallium, potassium, and cadmium) is occurring within the sediment of these lakes, thus obliterating any geochemical flood signal that may have been deposited in the sediment (Rasmussen et al., 1998). In contrast, the sediment from Salt Lake is well oxygenated and the water column is well mixed. The sediment column is well mixed by current and wave action, and the amalgamated sediment column does not record flood layers over time.

Significant differences in conductivity are observed between lake waters and the Red River (as measured in the late spring and early summer). The values measured at Horseshoe Lake and Lake Louise were much lower in 1997 than in 1998 or 1999. This may be due to the extended period and deeper level of inundation in 1997, which resulted in a more significant dilution (in salinity) of the lake waters.

Horseshoe Lake water has very elevated concentrations of potassium, sodium, and chlorine, and slightly elevated calcium, magnesium, and sulphate values, with respect to the Red River (Fig. 2). The lake is spring fed and local groundwater conditions are brackish (Betcher et al., 1995). The lake water is also enriched in boron, bromine, lithium, nitrite, and strontium, and depleted in fluorine, iron, manganese, phosphate, silica, and titanium, with respect to the Red River. The large difference in ion species concentration between Horseshoe Lake and the Red River could be used to detect flood deposits. The observed decreases in sodium, strontium, and boron in the Horseshoe Lake profile could represent flood deposits-events, but close examination of these profiles does not show any parallel shifts in any of the geochemical species (Medioli, 2001). In fact, sodium values are almost constant below a depth of 15 cm, and the apparent enrichment at the top of the core may be due to either decades of fertilizer runoff entering the lake basin or elemental cycling in the top of the sediment column. Alternatively, the increase in sodium may be due to changes in the groundwater geochemistry due to agriculture in the area.

Lake Louise water samples have significantly elevated concentrations of calcium, potassium, magnesium, sodium, and sulphate, and slightly elevated chlorine values (Fig. 2), with respect to the Red River. Lake Louise waters are also enriched in lithium, nitrite, sulphate, strontium, and uranium, and depleted in fluorine, iron, manganese, nitrate, phosphate, and silica, with respect to the Red River. Lake Louise salinity is not as elevated as that of Horseshoe Lake but is still significantly higher than that of the Red River. Geochemical profiles, however, do not show any consistent, parallel shifts in major ions (Medioli, 2001).

A significant decrease in conductivity was observed on a transect extending from Salt Lake across its outlet stream and the Park River to the Red River. A ten-fold difference in conductivity between Salt Lake and the Red River was documented, yet no significant downcore shifts in the major cations (calcium, magnesium, sodium, and potassium) were observed (Medioli, 2001).

The massive appearance of Lake Louise and Horseshoe Lake sediments may be due to the lack of textural differences that would make bedding visible. It is unlikely to be due to bioturbation, however, as infaunal benthos could not survive below the anoxic sediment-water interface, and any dysaerobic organisms living on the sediment bottom would live right at the sediment-water interface without disrupting it (Finlay, 1980; Wetzel, 1983). These lakes are quite shallow, and the persistence of anoxia on the bottom would seem to indicate that wind and wave action do not penetrate deep enough into the water column to disrupt the bottom (Wetzel, 1983).

Salt Lake has a very shallow basin. Its water column is well oxygenated year round due to its shallowness. The water column is easily mixed by wind and wave action, and the sediments are bioturbated, resulting in a more or less massive looking sediment core. The lake can become very shallow in the summer, and birds were seen wading near its centre. It is possible that the lake bed may even become completely exposed during extremely dry years, further disturbing the sediment bottom. The result of all these processes is the loss of most internal sedimentary structures.

The presence of sedimentary organic matter can be used to help identify sediment source. In all three lakes, Rock-Eval® pyrolysis reveals that organic matter is all Type III, or terrestrial in origin. This was quite surprising, as the lakes are eutrophic, and algal growth (Type II organic matter) within the lake basins is extensive in the summer months. It must therefore be concluded that a large part of the sediment supply to these lake basins is not autogenous (i.e. microbial and algal) but rather enters the lake basins from the catchment area. This may be due, in part, to deforestation on the river floodplain and around the lake basins (Brooks and Grenier, 2001). The sediment may enter as runoff from agricultural processes or from riverine sources during flooding. Flood sediment is a combination of river sediment and sediment suspended from fields during flooding. These sediments are rich in plant debris and result in deposition of Type III organic matter.

Sedimentation rates in Horseshoe Lake are quite high, averaging 3.2 mm/year. As the flood layers from 1997 indicate, however, this sedimentation can occur intermittently or as quickly as 3 cm over a period of a few weeks. This sedimentation rate is a bit higher than the rate of 2.5 mm/yr that Brooks and Grenier (2001) calculated for Lake Louise. Their calculation was based on a pollen chronology that placed the onset of agriculture at a depth of 30 cm. They also calculated a pre–European settlement sedimentation rate of 0.24 mm/yr at Lake Louise.

CONCLUSIONS

The primary objective of this study was to find a Red River flood record in the lake cores. No such record could be identified lithologically in any of the cores. The water geochemistry of the lake waters is significantly different from that of the river and offered promise for finding a geochemical flood history. Unfortunately, due to redox conditions in the sediment column, if any such record was deposited, it has since been obliterated. The organic geochemistry was also unsuccessful in identifying a flood record because the terrigenous input into the lake basins is far more significant than had originally been presumed. All lakes are dominated by Type III organic matter, which indicates significant external terrestrial sediment input despite the abundance of algal growth. In short, no flood record has yet been found in any of the three lake cores.

Lake Louise and Horseshoe Lakes are hypereutrophic lakes. Anthropogenic agricultural activities have resulted in phosphorus, nitrogen, and sodium enrichment in their water columns, which has, in turn, promoted algal growth in the spring and summer. This has resulted in the formation of at least seasonal anoxia at the sediment-water interface and anoxia, with metal cycling, within the sediment column. The chemical environment in the sediment column does not promote the preservation of geochemical flood signatures.

Salt Lake is a saline, well oxygenated lake outside the Red River valley. Its shallowness causes the water column and the top sediments in the lake basin to be resuspended by bioturbation, as well as by wind and wave action. This results in a flat geochemical profile and the obliteration of any flood deposits.

ACKNOWLEDGMENTS

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