Paleolimnology and global change on the southern Canadian prairies[1]

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Abstract: Field and laboratory work over the past two years has produced an extensive collection of sediment core data from lakes in southern Alberta, Saskatchewan, and Manitoba. Preliminary analyses, including physical description, photography and radiography, isolation of plant macrofossils, development of chronostratigraphy and lithostratigraphy, as well as documentation of current lake chemistry, morphology and drainage basin characteristics, indicate that significant water level and chemical variations have occurred during the Holocene over this broad geographic area. Because historic hydrological fluctuations in these prairie watersheds are closely related to the balance between evaporation and precipitation, climate is considered the driving force behind Holocene lake-level dynamics. Continued analyses are directed at producing a detailed reconstruction of long-term hydrological and climatic dynamics for the southern Canadian prairies.

Résumé : Le travail effectué sur le terrain et en laboratoire au cours des deux dernières années s'est traduit par un imposant ensemble de données sur des carottes de sédiments lacustres prélevées dans le sud de l'Alberta, de la Saskatchewan et du Manitoba. Les analyses préliminaires, qui comprennent une description physique, des photographies et des radiographies, l'isolement de macrofossiles végétaux, l'établissement de la chronostratigraphie et de la lithostratigraphie, ainsi que la documentation des caractéristiques chimiques, morphologiques et hydrographiques actuelles des lacs, indiquent que d'importantes variations du chimisme et du niveau de l'eau se sont produites pendant l'Holocène dans cette vaste région géographique. Comme les fluctuations hydrologiques historiques dans ces bassins hydrographiques des prairies sont étroitement liées à l'équilibre évaporation-précipitation, le climat est considéré comme la force qui a régi la dynamique du niveau des eaux durant l'Holocène. Les efforts continus d'analyse visent à reproduire en détail la dynamique hydrologique et climatique à long terme du sud des prairies canadiennes.

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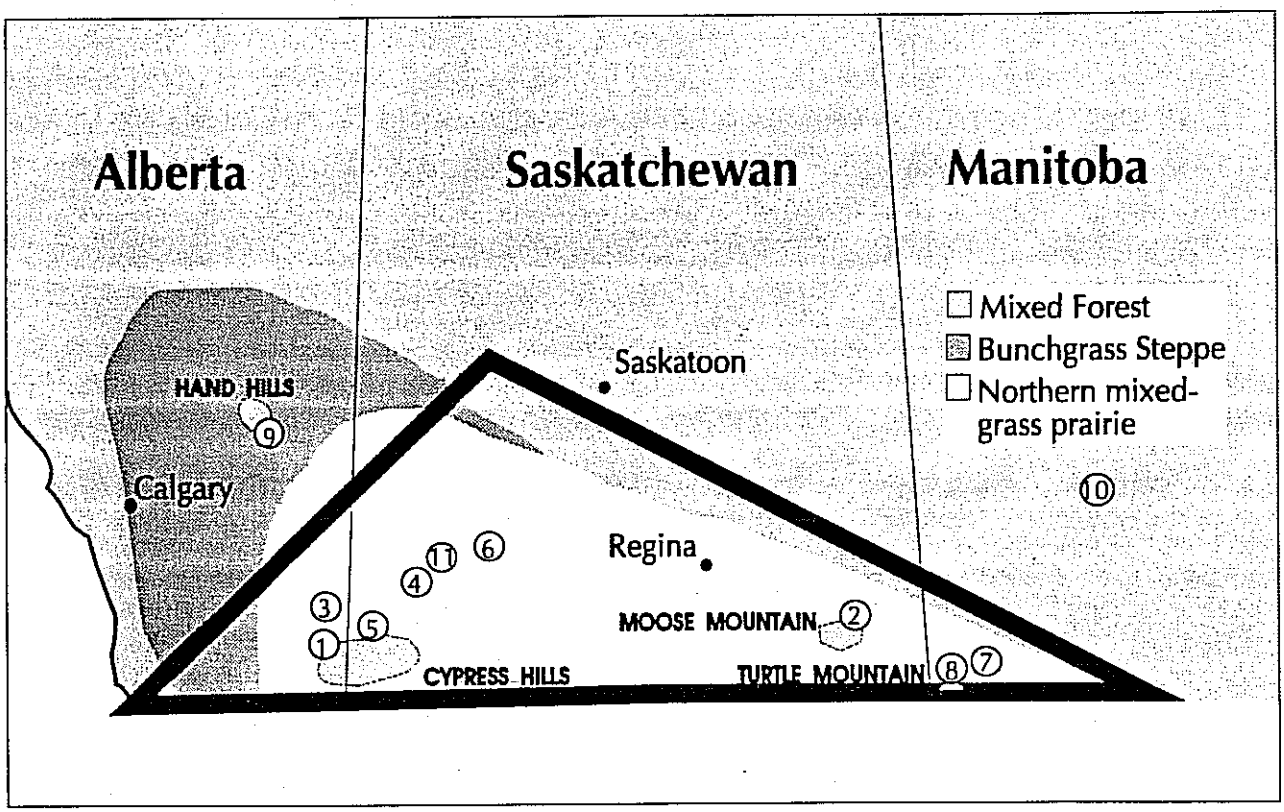
INTRODUCTION

In 1860, after four years surveying what was to become the heartland of Canada's wheat production, Cpt. John Palliser returned to Ottawa with the view that the semi-arid grassland of the western Canadian interior would be "forever and comparatively useless" (Spry, 1968). Ignoring Palliser's view, the Canadian government built the national railroad across Palliser's Triangle (Fig. 1), bringing a wave of settlement at the turn of this century (a time of abundant moisture, quite unlike the drought conditions that prevailed at the time of Palliser's expedition). The area has since become one of the world's most productive agricultural regions, despite enduring severe social and economic hardships during two decades of hot, dry weather in the 1930s and 1980s. These unusually warm, dry episodes, combined with global climate model (GCM) predictions of increased aridity in the North American interior due to increased greenhouse gas concentrations (Karl and Heim, 1991), have raised concern for the area's economic future. Although one hundred years of temperature records from the Canadian prairies support the view that the region is warming (Fig. 2), it is impossible to assess how this historic trend and computer model predictions compare to long-term climatic variability without consulting proxy climate records. Recognizing the importance of this perspective, the Geological Survey of Canada established the Palliser Triangle Integrated Research Monitoring Area (IRMA) to both produce a high resolution paleoclimatic record for the region and document the nature of landscape responses to a variety of past climatic regimes (Lemmen et al., 1993). This report summarizes progress to date on the paleoclimatic component of the Palliser IRMA.



Study sites

1 – Elkwater Lake
2 – Kenosee Lake
3 – Chappice Lake
4 – Antelope Lake
5 – Harris Lake
6 – Clearwater Lake
7 – Killarney Lake
8 – Max Lake
9 – Little Fish Lake
10 – Lake Manitoba
11 – Freefight Lake

Figure 1. Palliser Triangle IRMA and study site locations discussed in text. Extent of Palliser Triangle as described in Spry (1968), although in ecological terms this semi-arid region corresponds to the extent of northern mixed-grass prairie and brown soil zone in western Canada.

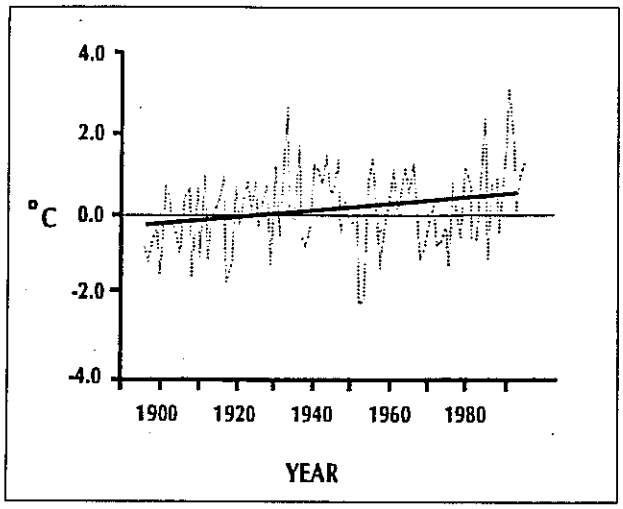


Figure 2. Prairie region temperature trend expressed as annual temperature departures from mean: 1895-1991 (adapted from Gullett and Skinner, 1992). Solid line indicates best-fit linear trend for the last century (trend significantly different from 0°C at the 95% level).

METHODS

With few of the most commonly used sources of proxy climate information available (for example, lengthy tree ring records, ice cores, etc.), development of a paleoclimatic record for Palliser's Triangle relies exclusively on sedimentary records from a select few of the numerous lakes in the region. The many saline and hyposaline lakes residing in poorly integrated drainages of recently deglaciated terrain (Last and Slezak, 1988), many displaying rapid responses to recent climate change (Hammer, 1990), contain archives of detailed proxy climate data within their sedimentary records. However, the ephemeral nature of most of these lakes, mineral-rich sediments typical of many of the basins and till containing carbonaceous shale, lignite and limestone produce significant problems in sediment sampling, developing accurate chronologies and obtaining uninterrupted stratigraphic sequences. These long-standing difficulties have hindered paleoeclimatic investigations in the entire Great Plains region of western Canada and northern United States (Barnosky et al., 1987; Last, in press b). To circumvent these problems, we have targeted spring-fed lakes on the prairie floor and large lakes on forested uplands for study, employed power assisted vibracoring techniques (Smith, 1992) to ensure collection of complete sedimentary records, and are relying solely on accelerator mass spectrometry (AMS) radiocarbon ages on seeds of upland and shoreline plants for chronological control. Where possible, we have arranged study sites in a series of transects emanating from the Cypress Hills (considered the hub of the Palliser Triangle), crossing climatically sensitive elevation, hydrological and vegetation gradients, ultimately linking our study sites with more extensively studied portions of surrounding regions.

Climate reconstructions will be based on regional lake-level and chemical responses to changes in the hydrological balance. The strategy used to reconstruct the paleohydrology of individual lake basins follows Digerfeldt's (1986) guidelines, utilizing multiple sensors in multiple cores from each lake. To accomplish these goals, a multi-disciplinary, co-operative approach to data collection and analyses has been adopted. GSC resources have been devoted to core collection, description, photography and X-ray imagery, as well as development of preliminary chronostratigraphies, lithostratigraphies and plant macrofossil stratigraphies for each core (Table 1). Remaining funds have been directed to graduate students working on specific paleoenvironmental parameters of the cores, under supervision of Canadian university collaborators with long-standing research interests in the study area. Others, although not receiving direct funding from the GSC, have accepted invitations to collaborate, increasing the breadth of data collected. In addition to the geochronology and lithostratigraphy described here, plant macrofossil, ostracode, diatom and gastropod stratigraphies will be developed at selected sites. Detailed study of the paleohydrology of the Great Sand Hills in southwestern Saskatchewan will also be undertaken. Investigation of the groundwater hydrodynamics of one study site (Chappice Lake) has recently begun, a venture that should serve as a launching point for additional hydrogeological research of other lakes in this study.

STUDY SITES

1. Elkwater Lake

Elkwater Lake straddles the climatically sensitive forest-grassland transition on the northwestern margin of the Cypress Hills. This relatively large (2.3 km^2) lake is fed by surface runoff and groundwater. A weir, built in 1908 (Mitchell and Prepas, 1990), regulates stream outflow resulting in stable, freshwater conditions that have established the lake as a popular resort. Irregular basin morphometry (Fig. 3.1), with two deep sharply contoured basins, mirrors the hummocky topography surrounding the basin.

Four sedimentary cores have been collected. Detailed studies on three of these cores, forming a transect from the deepest point of the main basin to its southern shoreline (Fig. 3.1), are currently underway. Cores EW1 and EW2 consist entirely of massive to crudely bedded silt and clay. Clay content increases with depth. Preliminary macrofossil analysis of core EW1 indicates that early lake history (ca. 5000-4000 BP) included a period of increased salinity, compared to present. This high-salinity phase was followed by a prolonged fresh, high-water stand. An attempt to date the onset of this high stand has been unsuccessful (the uppermost date on core EW1 is clearly too old, Fig. 3.1), presumably due to sampling ancient shoreline remains that were redeposited when lake-level increased.

In contrast to cores EW1 and EW2, near-shore core EW3 consists of sands interbedded with massive mud and organic-rich layers. Deposition rates are evidently much more rapid in the littoral zone than in the central lake area, particularly during the period from 550 to 325 BP. Rapid deposition here

Table 1. Summary of core information and analytical parameters at Palliser Triangle IRMA study sites.

	Elkwater	Kenosee	Chappice	Antelope	Harris	Clearwater	Killarney	Max	Little Fish	Manitoba	Freeflight
Core Description	X	X	X	X	X	X	X	X	X	X	X
Photography	X	X	X	X	X	X	X	X	X	X	X
Radiography	X	X	X	X	X	X	X	X	X	X	X
% H_2O	X	X	X	X	X	X	X	X	X	X	X
% Organic	X	X	X	X	X	X	X	X	X	X	X
% Carbonate	X	X	X	X	X	X	X	X	X	X	X
Particle Size	X	X	X	X	X	X	X	X	X	X	X
Mineralogy:											
Bulk	X	X	X	X	X	X	X	X	X	X	X
Detailed Carbonate & Evaporite	X	X	X	X	X		X			X	X
Detailed Clay			X	X						X	X
Geochemistry:											
Inorganic			X	X						X	X
Organic			X	X			X			X	X
^{13}C & ^{18}O			X		X					X	X
AMS ^{14}C	X	X	X	X	X	X	X	X	X	X	
Biostratigraphy:											
Plant Macro.	X	X	X	X	X	X	X	X	X		
Diatom	X	X			X		X			X	X
Ostracode	X	X	X	X	X					X	X

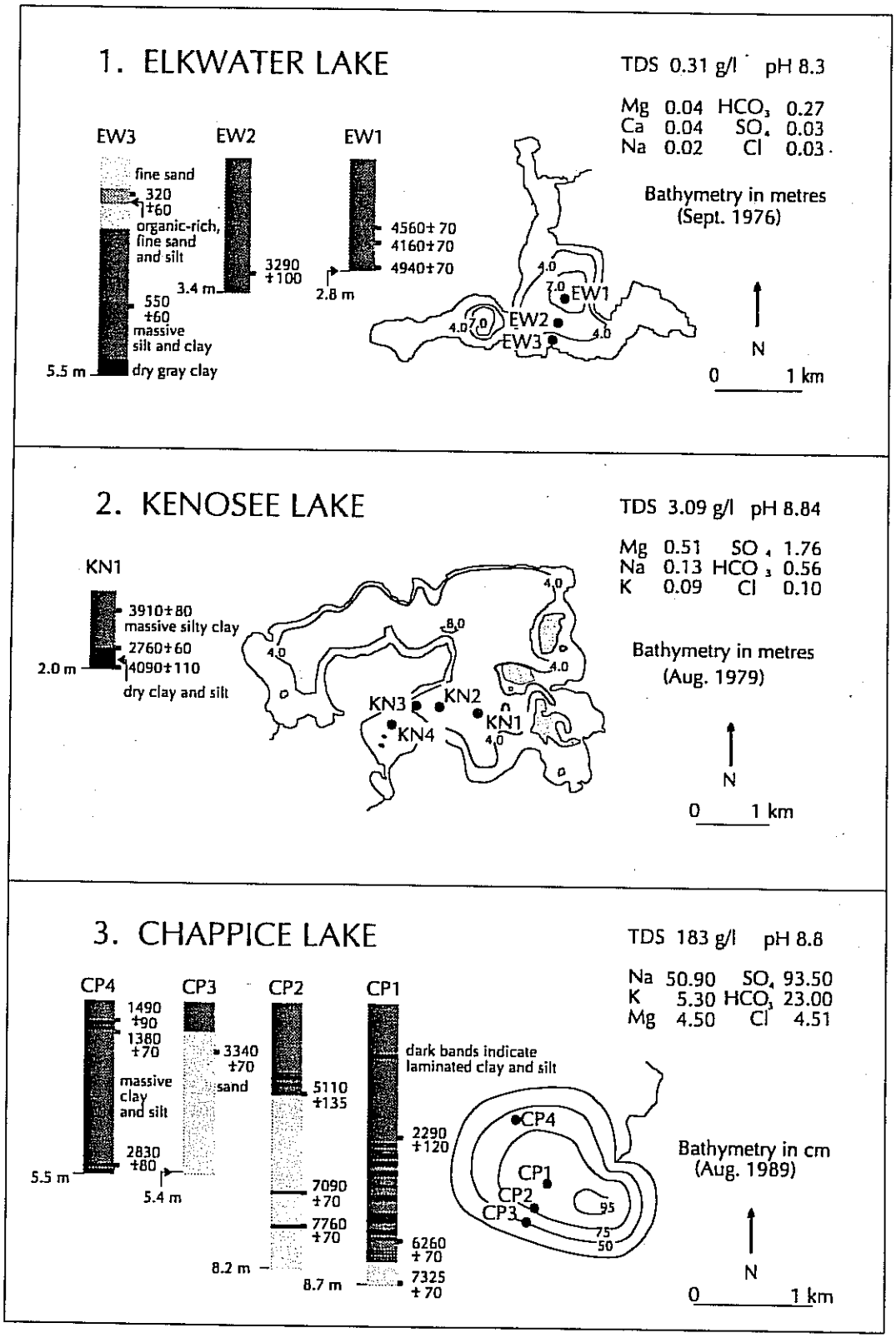


Figure 3. Bathymetry, water chemistry (where available), sediment stratigraphy, and geochronology of study sites discussed in text. Shaded areas within lake basins indicate islands.

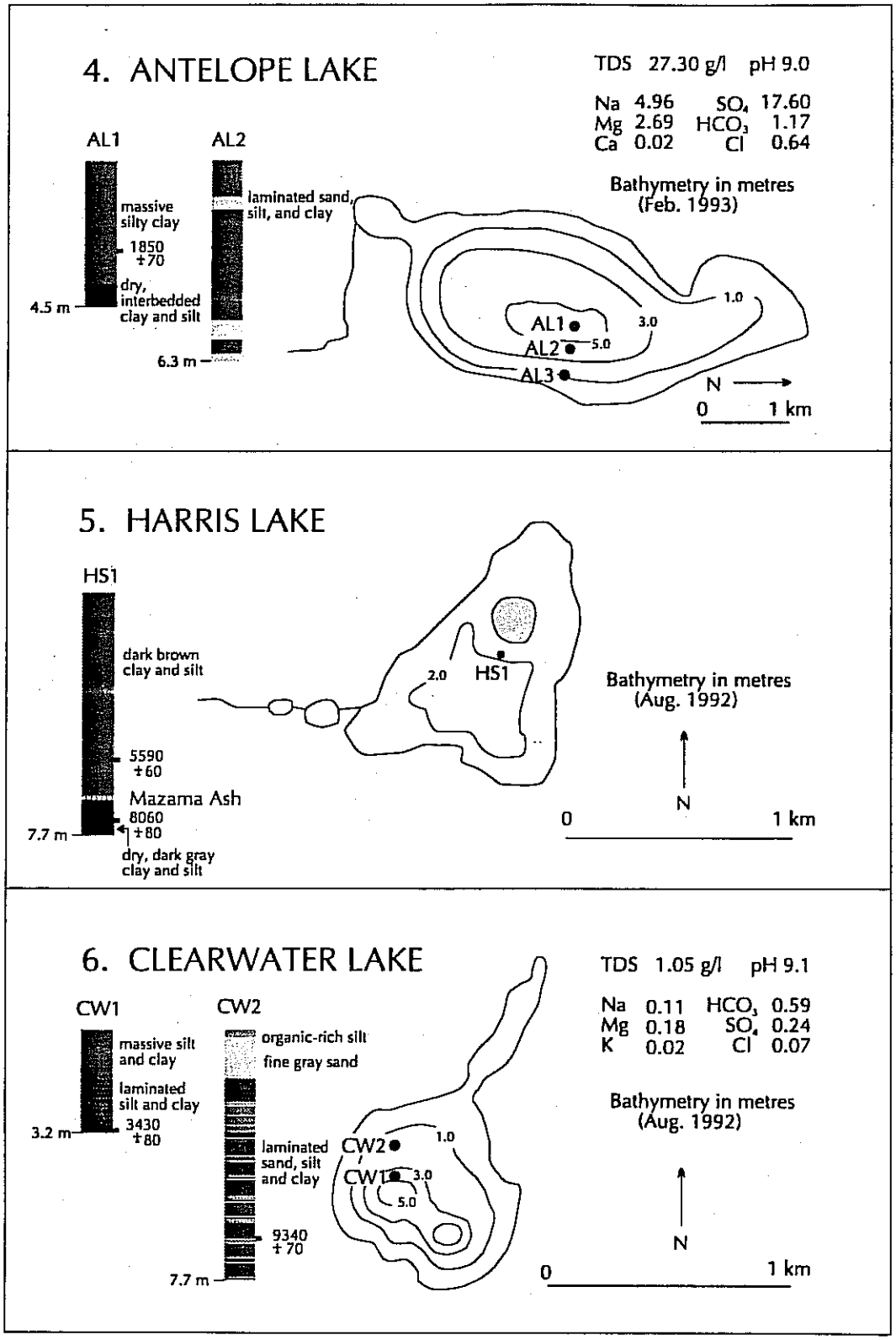


Figure 3. (cont.)

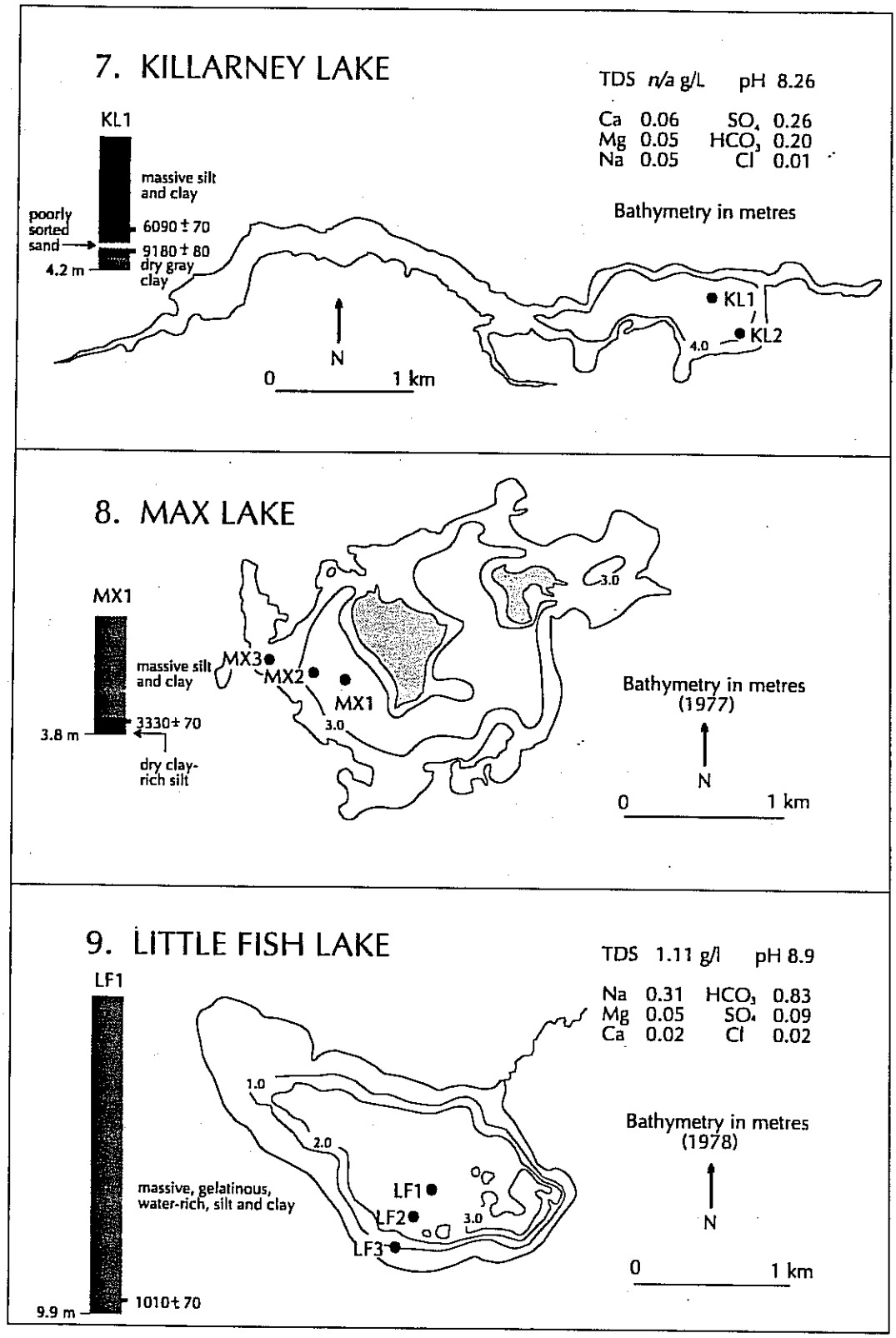


Figure 3. (cont.)

may relate to slope instability during the Little Ice Age, stimulated by climatic conditions similar to those of the cool, moist Neoglacial that increased the incidence of rotational landslides on the Cypress Hills (Goulden and Sauchyn, 1986).

In future, analyses of abundant gastropod and ostracode remains in these cores, along with continued plant macrofossil and mineralogical investigations, will be directed at documenting late Holocene lake-level and chemical variations, distinguishing periods of increased groundwater discharge and establishing a more precise chronology.

2. *Kenosee Lake*

Situated on a forested upland near the eastern limit of the Palliser Triangle, Kenosee Lake is now more saline than Elkwater Lake. Like Elkwater Lake, Kenosee Lake has become a popular recreation area, but declining lake levels and deteriorating water quality through the 1980s have created concern among land owners, provincial park officials and businesses established in the resort area at the north end of the lake (Aaston, 1983). Kenosee Lake is fed by groundwater and surface runoff. At present, outflow is restricted to groundwater discharge, as highway construction has blocked natural surface drainage to the southwest.

Three cores were retrieved from the deep southern embayment of Kenosee Lake in May 1992, and three near-shore cores were collected in March 1993. Four cores (KN1-4, Fig. 3.2) have been selected for detailed study. To date, preliminary analyses have been restricted to KN1. Macrofossil remains in this massive silty clay sequence (clay content increases and water content decreases with depth) indicate an early, high-salinity, low-water interval (ca. 4000-2700 BP), followed by lake freshening and a further water level rise in the upper 75 cm of the section. An attempt to date this most recent event resulted in an anomalously old date (the uppermost KN1 date, Fig 3.2). The error is again most likely the result of sampling ancient shoreline remains resuspended as water levels rose. Continued macrofossil and mineralogical study of these cores, complemented by diatom, ostracode and gastropod analyses, will be directed toward reconstructing paleohydrological conditions on the Moose Mountain upland, an important groundwater recharge feature of southeastern Saskatchewan (Różkowska and Różkowski, 1969).

3. *Chappice Lake*

The paleohydrology of Chappice Lake has been discussed in detail elsewhere (Vance, 1991; Vance et al., 1992, 1993). Recent investigations are focused on late Holocene events depicted in two cores (CP4 and CP5) collected in the area of highest known sedimentation rates in the basin (Fig. 3.3). Detailed macrofossil and mineralogical studies of CP4 are currently underway. In addition, mid-Holocene laminated carbonate sequences in core CP1 are being investigated to identify mechanisms involved in their genesis and stable isotope studies of this core are currently underway. Recent piezometer installations in the lake basin mark the first attempts to elucidate groundwater hydrodynamics in the watershed. Unfortunately, the highly alkaline water of the basin is not conducive to preservation of either diatoms or ostracodes, prohibiting the development of time stratigraphic sequences for these sensitive indicators of environmental change.

4. *Antelope Lake*

Situated on the southeastern margin of the Great Sand Hills, this relatively large, closed-basin saline lake may become one of the key basins in the Palliser IRMA, in terms of linking landscape processes and lake sedimentary sequences. Well defined layers of sorted fine sand in core AL2 raise the possibility of correlating these features to local dune activity. Detailed sedimentological investigations have been directed toward identifying the origin of these sand lenses. At the same time, water chemistry changes associated with lake-level dynamics depicted in plant macrofossil and lithostratigraphic records will provide a backdrop of climatic events associated with dune activity. As is the case in Chappice Lake, however, highly alkaline conditions prohibit diatom and ostracode studies.

5. *Harris Lake*

A single core was taken from a near-shore position in Harris Lake, a small groundwater discharge basin situated on the north flank of the east block of the Cypress Hills, to complement detailed pollen and lithostratigraphic analyses conducted on a central lake core from this basin (Sauchyn and Sauchyn, 1991; Last and Sauchyn, 1993). Plant macrofossil studies, mineralogical analyses and additional AMS radiocarbon dates on core HS1 will help delimit the magnitude and timing of lake-level fluctuations that accompanied Holocene environmental changes described by Sauchyn and Sauchyn (1991).

6. *Clearwater Lake*

Two cores have been extracted from the offshore area of this small, closed-basin lake originally investigated by Mott (1973). Although the lake has no inflowing stream or surficial outlet, the uncharacteristically low salinity of water in the basin (for an area of low precipitation and high evaporation rates), suggests that it is both receiving groundwater input (likely through subsurface springs in deeper sections of the lake) and discharging groundwater downslope to the north. A 9000 BP near-basal date on sedge seeds in CW2 and the finely laminated nature of the sediments suggest that development of a detailed, high resolution, long-term account of the lake's paleohydrology is possible. Moreover, excellent preservation of ostracodes, diatoms, and gastropods makes this an ideal site for analyzing multiple sensors. The record will complement ongoing plant macrofossil investigations of nearby early Holocene pond sediments by C. Yansa (University of Saskatchewan).

7. *Killarney Lake*

One other lengthy Holocene record from a freshwater lake on the eastern edge of the Palliser Triangle was recovered in March 1993. This elongate basin, occupying a glacier meltwater

channel, has recently been the subject of microfossil, pigment and chemical analyses to infer long-term trends in lake production (Richmond and Goldsborough, 1992). Detailed plant macrofossil and mineralogical analyses of the two new cores will complement this ongoing investigation by providing plant macrofossil and lithostratigraphic data pertinent to the basin's hydrological evolution, as well as outlining pace and amplitude of past climatic changes in southwestern Manitoba.

8. Max Lake

Situated 45 km southwest and 200 m above Killarney Lake on the Turtle Mountain Upland, Max Lake is a relatively large, freshwater, closed-basin lake. Its sedimentary record is a valuable complement to the Killarney Lake record, since Max Lake lies on the groundwater recharge feature closest to the groundwater discharge Killarney Lake site. The 3.8 m of massive mud collected at Max Lake is similar to the Kenosee Lake record from the nearby Moose Mountain Upland, both in terms of sediment type and temporal duration of the record. Moreover, preliminary macrofossil analyses indicate that an early low-water, high-salinity stand, like that evident in the Kenosee Lake record, also occurred at Max Lake. As at Killarney Lake, detailed macrofossil and mineralogical studies of the Max Lake cores will complement Richmond and Goldsborough's ongoing diatom and pigment studies.

9. Little Fish Lake

On the far western fringe of the Palliser Triangle, above the prairie floor on the Hand Hills upland, lies Little Fish Lake. This large (7 km^2) freshwater basin has been steadily declining in size through the 1980s, eliminating a once thriving fish population and reducing the lake's value as a recreation site. Three long cores were taken from the basin in January 1993. Core LF1 consists of gelatinous, water-rich, massive mud that is remarkably uniform in terms of grain size and mineralogy, and has an unusually low amount of plant macrofossil remains. A sedge seed recovered near the base of the 9.9 m sequence yielded an AMS radiocarbon age of *ca.* 1000 BP. This is an extremely young age for such deeply buried material and, together with the uniform composition and texture of the sediment, suggests that the lake is a site of vigorous groundwater discharge sufficient to redeposit and mix the sedimentary record. Thus, the Little Fish Lake sequence will not likely yield undisturbed, high-resolution data and no other analyses are planned. Hand Hills Lake, a shallow, ephemeral, closed-basin 10 km north of Little Fish Lake will be cored early in 1994 to provide a record from this area that currently constitutes a critical gap in coverage between sites in southeastern Alberta and the extensively studied Aspen Parkland of central Alberta (Schweger and Hickman, 1989).

Other study sites

Two additional lakes have been cored as part of Palliser Triangle IRMA field activities. Lake Manitoba lies beyond the northeastern margin of northern mixed-grass prairie, but is the only major drainage basin of the Palliser Triangle area that has previously been the subject of intensive study (Teller and Last, 1990). Analyses of the 4.8 m long core in collaboration with researchers involved in this ongoing investigation will help define hydrological responses in one of the region's major watersheds to late Holocene climatic change. Freefight Lake, on the other hand, lies in the heart of the driest portion of the Palliser Triangle. The 2.6 m long core recovered from this basin, the first retrieved from the offshore area of this deep (mean depth = 20 m), hypersaline, meromictic lake (Last, in press a), consists of finely laminated carbonate mud interbedded with massive salt deposits. Analyses of this sedimentary record will offer insights into the evolution of this unique lake as well as providing a high resolution record of hydrological change in the Great Sand Hills during the late Holocene.

In addition to coring Hand Hills Lake, the 1994 field season will be devoted to recovery of records in the Old Wives Lake drainage basin of southern Saskatchewan, filling another gap in geographic coverage. Cores of recent sediment will also be collected from two study sites for detailed analyses directed at relating recent stratigraphic variation in paleolimnological indices to historic events within each watershed.

CONCLUSIONS

Paleolimnological records in the southern Canadian prairies have been, until recently, an underutilized archive of detailed information on past hydrological and climatic change in this important but climatically sensitive agricultural region. In the century following European settlement, the area has been subjected to dramatic fluctuations in climate, from decades of devastating drought to periods of abundant rainfall. The application of new approaches and techniques to the recovery and analysis of numerous sedimentary records spanning this semi-arid grassland has opened the door to development of the first detailed record of past climate change for this economically important region of Canada. Coupled with documentation of geomorphic responses to climatic extremes, results of the Palliser IRMA will provide a much needed record of the varied landscape responses that the area has experienced over the last several millennia, giving land use planners and policy makers a realistic view of the range of extremes experienced in the past, their frequency of occurrence, and ultimately clues regarding the nature of changes western Canadian's face in future.

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