PCAG'98 FIELD TRIP GUIDE

FIELD TRIP LEADERS:

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examples of these landforms along the way from Watrous to Simpson. Arcuate ridges oriented at right angles to regional ice flow have been interpreted as **crevasse fillings**. These features are believed to form by the melt-out and accumulation of surface debris within crevasses near the margin of glaciers. We may observe examples of these landforms along the way from Nokomis to Drake.

For the most part our route traverses a landscape characterized by gently rolling topography with local relief commonly less than 5 metres. The Assiniboine River Plain in this region is composed largely of glaciofluvial (sand and gravel) and glaciolacustrine (silt and clay) sediments deposited by meltwater generated by the decay of the Laurentide Ice Sheet. Meltwater eroded deep (up to 50 metres), broad (up to 300 metres) valleys (i.e. **glacial spillways**) into the underlying glacial till. Little Manitou Lake (**Stop 1**), Boulder Lake and Last Mountain Lake (**Stop 2**) lie within one of these spillways (Watrous - Last Mountain Lake spillway; **see Location Map**). Glacial spillways served as conduits for the transfer of meltwater from the margin of the Laurentide Ice Sheet into several **glacial lakes**; Lake Elstow, Last Mountain Lake, and the Quill Lakes. Meltwater streams flowing within the spillways deposited coarse-grained sediments within their channels. These sediments are preserved as **river terraces** along the margins of former spillways. Where meltwater streams entered glacial lake basins large **deltas**, consisting of sand and gravel up to 15 metres thick, were constructed. We will observe one of these former deltas at the second stop on our trip. Fine-grained sediments, consisting of up to 5 metres of silt and clay, were deposited from meltwater entering glacial lakes. We will observe these glaciolacustrine sediments along the route between Simpson and Nokomis and between Drake and Manitou Beach.

STOP 1: LITTLE MANITOU LAKE

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"The water has been compared to 7% solution of Epsom Salts and is reported to perform very well as a fast and effective laxative..." Appleby & Green (1986).

Little Manitou Lake, located about 100 km southeast of Saskatoon, occupies a relatively large, steep-walled glacial meltwater outwash channel. Despite the fact the communities immediately surrounding the basin have a long history of intensive recreational development dating as far back as 1910, relatively little is known of the limnology, hydrology, or geology of the lake. Although the number of resort facilities adjacent to the lake has declined since the 1950's, the area is still a popular and attractive tourist destination. Historically, the lake has also been the site of mineral salt and brine shrimp harvesting. Until 1981, the sulfate salts of mirabilite, bloedite, and epsomite were collected, bagged, and shipped to Winnipeg, Manitoba, where they formed the major ingredient in the 'curative and therapeutic' waters of Uhlman's Health Spa on Main Street.

Water Chemistry

Perhaps one of our first tasks at this stop should be to dispel some of the erroneous beliefs, exaggerations, and outright fabrications that seem to surround Little Manitou Lake. The water does *not* have a "density greater than that of the Dead Sea" (Leader-Post, 1990) nor is the chemistry even remotely similar to either the Dead Sea (Saskatchewan Tourism tourist brochure) or the ocean (The Great Saskatchewan Vacation Book, 1992). The lake basin is *not* "glacier-carved" and, although groundwater plays an important role in the hydrochemical budget, the lake cannot be classified as "spring-fed". Finally, the lake is *not* the "saltiest in western Canada" (or even in Saskatchewan), nor is it the "deepest" (or "shallowest") saline lake in the region.

The long-term average water composition of Little Manitou Lake brine is shown in **Table 1**. The water of the lake is, indeed, difficult to characterize, not because of any unusual or unique properties but rather because the lake has experienced dramatic fluctuations in both concentration and composition during historic times. Since the first published analyses in the early 1920's, the salinity has varied by nearly 200%. During the period 1921-1949, the brine increased in concentration from less than 70 ppt TDS to over 200 ppt; since the early 1960's the lake has been artificially freshened by diversion of Saskatchewan River water. However, even with this freshening, the bottom waters during most of the past decade have been about 200 ppt. Furthermore, pre-diversion seasonal fluctuations in composition were dramatic. Cooling of the brine during periods of relatively high concentration resulted in massive subaqueous precipitation of hydrated Na and Mg sulfate salts, such as epsomite ($MgSO4.7H20$), mirabilite [$Na_2(SO_4)2.10H20$], and bloedite [$MgNa_2(SO_4)_2.4H20$]. This seasonal precipitation of salts was so great that the lake regularly alternated between a $Na-SO_4$ and a Mg-Cl brine type. This annual sulfate salt precipitation is further enhanced by freeze-out concentration and precipitation of salts during the winter under the thin ice cover. The annual layer of salts precipitated can be as much as 50 cm thick. Most of this very soluble material is re-dissolved upon melting of the ice (causing dilution) and warming of the brine during spring. However, our coring and monitoring of Little Manitou indicates a substantial thickness of salt has been preserved in the central part of the basin, and that in any given year not all of the seasonally precipitated salts are necessarily taken back into solution. This seasonal precipitation - dissolution process also has interesting and profound effects on the stratification character of the brine and on the heat budget characteristics of the lake.

Modern Sediments and Stratigraphy

The basin is flat bottomed with very steeply sloping sides. The modern bottom sediments exhibit a simple facies pattern: a narrow band of poorly sorted, coarse (sandy gravel to silty sand) siliciclastics in the near shore area grades basinward into clayey salt and salt in the deep water (>3 m depth) offshore area. The offshore sediments are composed mainly of soluble evaporitic minerals dominated by epsomite, bloedite, and mirabilite. The offshore areas of the lake are presently experiencing very high rates of sedimentation of these salts, with annual rates (measured by sediment traps) of up to nearly 30 kg m^{-2}. In detail, the mineralogy and paragenesis of these endogenic salts are complex and the modern sediments include a wide variety of Ca, Mg, Na, and Fe sulfates. The lake contains about 2 million tonnes of industrial grade Na and Mg sulfates.

Our knowledge of the Holocene stratigraphic sequence preserved in this lake is still incomplete. We have recovered sediment cores of up to 2.5 m in length from 11 sites in the offshore area of the basin. The oldest sediment penetrated to date is only about 2000 years old. All coring sites were in water depths greater than 4 m, so we still have no understanding of how these deep water sedimentary facies relate to the coarse clastics of the near shore areas. This offshore sedimentary sequence ranges from fine-grained, organic-rich mud and poorly sorted, clayey, sandy silt to coarsely crystalline, well-indurated salts. Five lithofacies can be recognized as shown in a typical composite lithostratigraphic section in **Figure 1**. The **basal structureless clay (Facies E)** is firm and non-bedded, and passes sharply upward into about 50 cm of gypsum ($CaSO_4.2H_2O$) and indistinctly **laminated gypsiferous mud (Facies D)**. Interfingering with this gypsum-rich facies is a black, **organic-rich, highly reducing mud (Facies C)**. Overlying Facies C and D is a **carbonate-rich mud (Facies B)** characterized by irregularly-spaced packages of finely-laminated sediment alternating with nonbedded material. The carbonate is mainly aragonite and this aragonite often has a distinctive "rice grain" crystal morphology (**Figure 2**). Occasional large granules and pebbles, probably of dropstone origin, also occur in Facies B. Finally, the uppermost sedimentary facies in the offshore area of the lake consists of **soluble salt.** This salt is generally clear, colorless, and nonbedded, but even small amounts of mud and organic matter can give a grey to black coloration. Although **Facies A** is, overall, dominated by Na sulfate minerals, the proportions of the major compositional groups (i.e., Na sulfates, Mg+Na sulfates, and Mg sulfates) show consistent stratigraphic variation: the lower third of the facies has a relatively high proportion of Mg sulfates. These salts grade upward into several tens of cm of mixed Na and Na+Mg salts, and, finally in the uppermost part of the facies, back into more Mg sulfate-rich precipitates.

The sediments recovered in our coring to date show the lake has undergone significant changes in salinity, composition, and water depth during the past several millennia. The oldest sediments (Facies E) were deposited in a relatively deep and freshwater lake that existed in the basin about 2000 years ago. Soon after 2000 BP, hydrologic conditions in the basin changed abruptly, water levels dropped, and the lake became a shallow to ephemeral mudflat/salt flat or playa basin. The water in this lake was compositionally complex and reflected a varying mixture of shallow, hyposaline Ca-SO_4 groundwaters and more alkaline, highly concentrated hypersaline surface brines. These low water/playa conditions existed in the basin until about 1500 BP, at which time the lake gradually deepened and eventually a perennial lake was re-established. Water depths for the next 500-700 years may have been as much as 20 m, and the lake was probably chemically stratified (**meromictic**). The rice grain aragonite indicates that the precipitated carbonate crystals settled through a relatively deep and slightly undersaturated monimolimnion. Water salinity began to increase about 1000 BP, probably associated with an overall lowering of lake levels. For the past millennium conditions in the Little Manitou Lake basin have likely been similar to that of today e.g., a perennial lake about 5-6 m deep with moderate seasonal fluctuations and occasional meromixis).

FIG. 1 Composite late Holocene stratigraphic section from Little Manitou Lake

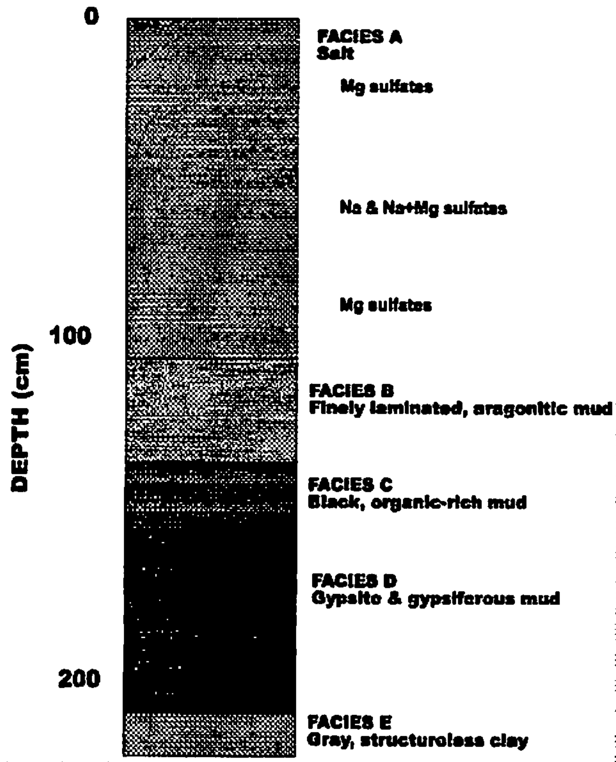

TABLE 1:
Little Manitou Lake Vital Statistics

Surface Area (A)	13.9 km^2
Drainage Basin Area	169 km^2
Maximum Length (L_{max})	20.1 km
Maximum Width (W_{max})	1.1 km
Maximum Depth (z_{max})	6.1 m
Mean Depth (z_{mean})	4.0 m
Volume (V)	169 $10^6 m^3$

	mg L^{-1}	mmol L^{-1}
Ca^{2+}	882	22
Mg^{2+}	17,091	703
Na^+	11,035	480
K^+	782	20
HCO_3^-	1098	18

	$mg\ L^{-1}$	$mmol\ L^{-1}$
SO_4^{2-}	71,181	741
Cl^-	16,131	455
TDS	179.1 ppt	
Ionic Strength	1.86	
pH	9.1	
Total Alkalinity	20.43 meq	
Carbonate Alk.	20.41 meq	

FIGURE 2. Aragonite crystals exhibiting "rice grain" morphology.