

# **SLEADS\* WORKSHOP 87**

## **SALT LAKES IN ARID AUSTRALIA**

**Arid-zone hydrology, geochemistry, stratigraphy and  
palaeoenvironments**

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**\* Salt Lakes, Evaporites and Aeolian Deposits**

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# GEOLIMNOLOGY OF AN UNUSUAL SALINE LAKE IN THE GREAT PLAINS OF WESTERN CANADA

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## Introduction and Setting

The Great Plains of western Canada and northern United States contain thousands of saline, hypersaline and brackish water lakes. Freefight Lake represents an end member in a continuum of salt lakes in this region. It is relatively deep and meromictic with a hypersaline Na-Mg-SO<sub>4</sub>-HCO<sub>3</sub> brine. The modern lake offers a rare opportunity to study a considerable range of geolimnological features, including playa/mudflat sedimentation and diagenesis, organic matter and organic carbonate production in a hypersaline environment, inorganic carbonate precipitation and diagenesis, and deep- versus shallow-water salt precipitation. Because the basin is closed and the water column permanently stratified, the postglacial sedimentary sequence also offers good potential for palaeoenvironmental studies. Finally, the basin represents the only known modern analog to some of the large and economically important sodium sulphate deposits that occur in the region. The purpose of this paper is to present an overview of the modern sedimentological geochemical processes and facies present in this unusual salt lake.

Freefight Lake is located in the northern Great Plains of western Canada about 350 km east of Regina, Saskatchewan. This region experiences a cold continental semi-arid climate. Mean daily temperature during January is about -17°C; during July it is 18°C. High winds and low rainfall during the ice-free season lead to high evaporation/precipitation ratios. The lake occupies a narrow closed basin that was created by glacial meltwater runoff about 15,000 years ago. Pleistocene glacial, fluvial and lacustrine deposits up to 150 m thick mantle the Tertiary and Cretaceous bedrock.

## Morphology, Hydrology and Limnology

Table 1 summarizes the morphological and hydrochemical features of Freefight Lake. With a mean depth of 14 m and maximum depth of nearly 25 m, Freefight is unusually deep compared to other prairie lakes. Morphologically, the basin consists of two distinct parts: the main permanent lake (area of 2.6 km<sup>2</sup>) and the seasonally flooded margin (1.5 km<sup>2</sup>). The lake has a flat bottom with very steep sloping sides. Several wave cut scarps and beach ridges occur on the walls of the valley above the present level of the lake. There is also bathymetric evidence of a submerged terrace at 10m depth.

Unfortunately, the hydrology of Freefight Lake is still largely unknown. The area receives about 28 cm of precipitation per year, but 4-5 times this amount can be lost through evaporation. The lake also receives water from diffuse runoff and a small ephemeral stream. The largest components of the hydrologic budget appear to be groundwater input and loss by evaporation. There are numerous subaerial springs and areas of diffuse groundwater discharge located within the

basin. It is also likely that subaqueous spring discharge occurs. The basin is topographically closed.

The water column in Freefight is chemically stratified with a chemocline existing at about 6 m depth. The mixolimnion, which in turn is also thermally stratified, averages 124 ppt TDS; the monimolimnion has a salinity of 175 ppt. Both water masses are dominated by Na and  $\text{SO}_4$ , however the monimolimnion has a higher proportion of  $\text{HCO}_3$  relative to the mixolimnion. The surface waters are alkaline (pH 9.2) but grade downward to a pH of 7.8 at the bottom. The lower water mass is strongly reducing, anoxic and highly charged with  $\text{H}_2\text{S}$ . During the ice-free season the lake shows an unusual temperature profile with a temperature minimum of 1-2°C occurring at the chemocline. This is likely due to the influx of cold but relatively fresh water into the lake from marginal and subaqueous springs. Another explanation may be a decrease in temperature caused by dissolution of mirabilite which is a strongly endothermic reaction.

#### Modern Sedimentary Facies and Processes

The modern surficial sediments of Freefight Lake are quite diverse, ranging from gravels and coarse sands to fine, organic-rich clays and coarsely crystalline salts. Several major environmental zones can be easily recognized in the basin giving rise to 8 sedimentary facies. Although the facies are visually and compositionally distinct and can be mapped, facies boundaries are commonly gradational.

The colluvium facies occurs at the base of the steep slopes of the valley and usually grades laterally into the mud flat and sand flat facies. The colluvium consists of a chaotic mixture of coarse and fine clastic material that has been derived from adjacent till banks by creep and mass wasting. The mud flat/sand flat facies in Freefight is unusually extensive, occupying about 40% of the total basin area. This sediment consists of well laminated quartz and carbonate silt and clay to non-bedded gypsum-rich sand. The mud flat facies is usually covered by efflorescent crusts.

Fine to coarse sands of the stream facies are present in isolated patches associated with the ephemeral stream. Evidence that this stream was once much more active is the occurrence of a relatively large delta at the east end of the basin. In addition to the beach ridges and terraces on the valley walls, the present lake is ringed by modern strandline features. These consist of low (up to 75 cm) beaches and mounds of carbonate and organic debris. The beaches are best developed on the downwind (east and south) edges of the basin.

The mud flat and beach facies pass basinward into a complex algal mat-carbonate platform/shoal facies. The sediments of this facies range from well laminated carbonate and quartz sands to organic-rich carbonate mud. Much of the lake bottom near the shore is dominated by microbial mats and stratiform stromatolites. Further offshore at the break in slope, this carbonate bank grades into a debris slope and fan facies. The sediment here consists of poorly sorted and often organic-rich sand and gravel. Finally, in water depths greater than about 8 m the bottom sediments consist of coarsely crystalline mirabilite mixed with fine grained organics, pyrite and clays.

The process sedimentology of Freefight Lake is still not fully understood. The minor amount of coarse clastics being delivered to the basin are deposited either on the mud flats or within the stream/delta complex. The extensive mud flats are also sites of clastic and chemical sedimentation during seasonal floods and evaporative concentration/pumping during exposure. Most of the sediment that is deposited in the main permanent lake is endogenic or authigenic in origin being, derived from inorganic precipitation within the water column or organically induced precipitation in the shallow water carbonate factory.

Work is continuing on Freefight Lake in four main areas: (a) stratigraphy and postglacial evolution of the basin; (b) origin of meromixis and source of salts; (c) modern water and sediment budgets; and (d) the generation and preservation of organic matter in this sulphate lake.

**Table 1. Morphological and chemical data for Freefight Lake**

Surface Area		
at mean water level	2.6 km	
at seasonally flooded level	4.1 km	
Depth		
Mean	14.1 m	
Maximum	24.9 m	
Brine Chemistry (mol/l):		
	Mixolimnion	Monimolimnion
Ca	0.006	0.009
Mg	0.435	0.501
Na	0.701	1.306
K	0.060	0.066
Cl	0.195	0.198
HCO <sub>3</sub>	0.051	0.265
SO <sub>4</sub>	0.707	0.953
TDS (ppt)	124	174
pH	9.2	7.8