RECENT MAGNESITE-HYDROMAGNESITE SEDIMENTATION IN PLAYA BASINS OF THE CARIBOO PLATEAU, BRITISH COLUMBIA

(92P)

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INTRODUCTION

Deposits of sedimentary magnesite and hydromagnesite of Holocene age are common on the semi-arid Cariboo Plateau of interior British Columbia. They occur as surficial deposits in playas and many other small closed depressions, mainly between Williams Lake and Clinton.

Reinecke (1920) and Cummings (1940) have provided the only descriptions of the deposits to date. Grant (1987) has reviewed these and other occurrences. Recent studies of Cariboo playa sedimentation have shown that magnesium carbonates are far more widespread than previously reported (Renaut and Long, 1987, 1989). Although Reinecke and Cummings speculated upon their genesis, no attempts have been made to determine their mode of formation and the age of the deposits.

Therefore, during June and July 1990, we began a study of the origins of the magnesite and hydromagnesite. This included a reconnaissance to determine the types of occurrence, and a detailed survey of Milk Lake, a small playa basin where they are well developed. We summarize results of the fieldwork at Milk Lake and provide some preliminary mineralogical data. These show that magnesium carbonates are probably forming in many Cariboo basins today, both subaqueously and in zones of shallow groundwater discharge.

GEOLOGY AND ENVIRONMENTAL SETTING

The intermontane Cariboo Plateau (Figure 3-3-1) lies at an elevation of 1050 to 1250 metres above sea level. The plateau is underlain mostly by Neogene basalts (Campbell and Tipper, 1971; Mathews, 1989), with a thin (0 to 5 m) mantle of till and glaciofluvial sediments (Tipper, 1971; Valentine and Schori, 1980). Ice retreated from the region about 10 000 years ago (Fulton, 1984). The adjacent Marble Range (Figure 3-3-1) is composed of marine sediments, basic lavas and ultramafic rocks of the Permian-Jurassic Cache Creek Terrane (Monger, 1989). Inliers of Cache Creek rocks occur locally within the plateau basalts (*e.g.* hills northwest of Meadow Lake).

The plateau surface is gently undulating with extensive coniferous forest cover, locally broken by grassy meadows. Drainage is disordered with few streams, abundant marshy ground, and several thousand lakes, both fresh and saline.

The climate is semi-arid to sub-humid with a mean annual precipitation of 300 to 400 millimetres, which is a similar value to the mean annual moisture deficit (Valentine and Schori, 1980). Mean July temperatures range from 13 to 17°C, compared with −9 to −11°C in January. Less than 90 days each year are frost free. Snow and ice usually cover the plateau from November until late March. Further details of the environmental setting are given in Renaut and Long (1989).

THE PLAYAS AND SALINE LAKES OF THE CARIBOO PLATEAU

There are more than one thousand saline lakes on the Cariboo Plateau, ranging from small ephemeral ponds and playas to large perennial meromictic lakes. Commonly they lie in small, closed basins between elongate mounds of till or eskers, or in small, kettle-like depressions. Many are clustered along paleomeltwater channels produced during the last deglaciation. Most lakes have small catchments, lack channelled inflow, and are fed directly by groundwater, snowmelt and unchannelled wash. Subaerial and sublacustrine springs are present at several lakes.

Although extensive magnesite-hydromagnesite deposits are also found around the margins of only a few perennial saline lakes (*e.g.* Meadow Lake, Figure 3-3-1), they are most common in the ephemeral lake (playa) basins. The playas are defined as those lakes that desiccate annually or every few years.

Three main groups of playas have been recognized (Renaut and Long, 1989; Renaut, 1990a):

- *Siliciclastic playas* are small and fed predominantly with clastic debris derived from slopewash and small slope failures.
- *Carbonate playas* are very shallow, alkaline lakes that desiccate producing hard, dry mudflats composed predominantly of carbonates, but with a peripheral zone of mixed carbonate and siliciclastic debris.
- *Saline mudflat – ephemeral lake complexes* have mixed carbonate-siliciclastic mudflats surrounding a shallow brine or pan in which salts (natron, mirabilite or epsomite, according to brine composition) are precipitated.

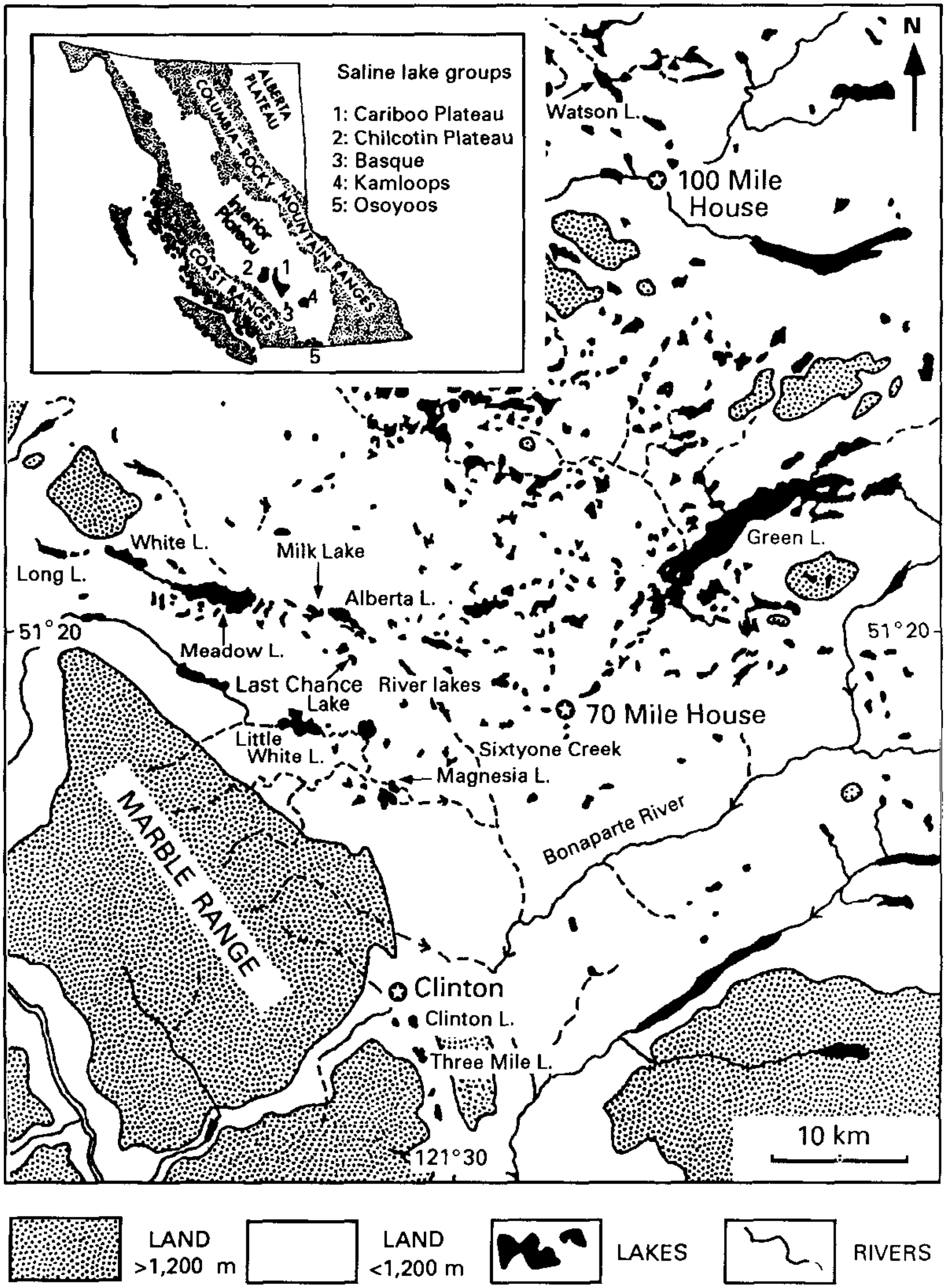

Figure 3-3-1. The southern Cariboo Plateau showing the location of Milk Lake.

More than 150 analyses have been made of Cariboo Plateau waters (Topping and Scudder, 1977; Renaut and Long, 1987; Renaut, 1990b). These have demonstrated a very wide range, both in salinity (<1 to >350 g L^{-1} TDS) and in chemical composition. Notable are the exceptionally high magnesium/calcium ratios, which range from 0.7 to greater than 300. Evaporative concentration appears to be the dominant method of increasing salinity.

The main ions in runoff, spring waters, and fresh lakes (<3 g L^{-1}) are usually Mg^{2+}, Na^{+}, HCO_3^- and SO_4^{2-}, and in many, Mg^{2+} and HCO_3^- are dominant. Lake waters with moderate salinities (3 to 50 g L^{-1}), including several carbonate playa-lakes, also have similar compositions.

There are three main types of hypersaline brine (>50 g L^{-1}) on the plateau: highly alkaline brines (pH: 8.5 to 10.5), poor in calcium and magnesium, with $Na\text{-}CO_3\text{-}(SO_4)\text{-}Cl$ composition; more neutral brines (pH: 7.5 to 8.8), poor in HCO_3 and CO_3, with $Mg\text{-}Na\text{-}SO_4$ composition; and $Na\text{-}Mg\text{-}SO_4\text{-}CO_3$ brines with somewhat lower salinities (pH: 8.0 to 9.5). The origins of the brines are discussed in Renaut (1990b).

THE MAGNESITE-HYDROMAGNESITE DEPOSITS OF MILK LAKE

A reconnaissance of magnesite and hydromagnesite deposits across the plateau suggests that they are found in four main depositional settings: (1) as the dominant minerals in carbonate-playa basins, where they precipitate subaqueously and in zones of shallow groundwater discharge; (2) in peripheral mudflats surrounding closed perennial lakes (*e.g.* Meadow Lake, Watson Lake of Cummings, 1940); (3) in marshy valley-bottom sites (*e.g.* Clinton, Basque, Riske Creek); and (4) either alone or associated with other mineral precipitates in saline mudflat – ephemeral lake complexes, where they may occur in peripheral mudflats or near sites of spring water discharge (*e.g.* Last Chance Lake).

Only the first type will be discussed here, using the example of Milk Lake. However, the processes in the mudflats of Types 2 and 3 are believed to be similar to those operative in Type 1.

SETTING OF MILK LAKE

Milk Lake is a small carbonate playa with well-developed magnesium carbonate muds (Figure 3-3-2). It lies on part of a southeast-trending paleodrainage channel network that extends from Long Lake, through Meadow Lake and Alberta Lake, and continues through to Sixtyone Creek (Figure 3-3-1). Large hydromagnesite-magnesite deposits are found west of Meadow Lake (Reinecke, 1920) and are reported in Sixtyone Creek (Cummings, 1940). It appears, therefore, that Milk Lake is but one of several magnesite-hydromagnesite lake basins located along the paleochannel.

Milk Lake has an irregular shape, consisting of three elongate lobes and a broad, central playa flat. It has a surface area of 0.3 square kilometre and the playa floor lies at an elevation of approximately 1095 metres. The playa is confined by low vegetated hills, composed of glacial deposits, that rise abruptly from the shoreline on all sides. At the northwestern margin, the valley continues across a low col, now crossed by a road (Figure 3-3-2). The eastern margin of the basin is defined by the Alberta Lake esker, which rises 10 to 15 metres above the valley floor. Several smaller ephemeral lakes are separated from Milk Lake by vegetated carbonate mudflats.

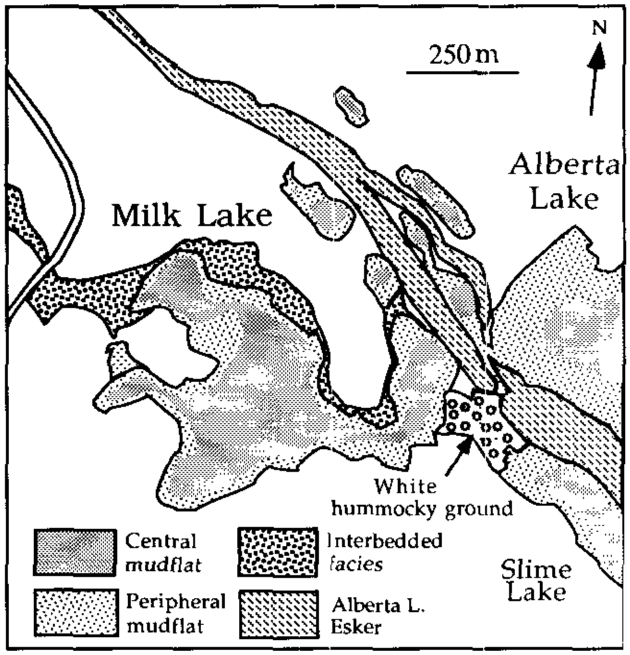

Figure 3-3-2. Depositional subenvironments of the Milk Lake playa basin.

The lake is fed mainly by groundwater, direct precipitation and unchannelled wash. Small lake-floor spring seeps are periodically visible. Milk Lake normally only holds water for 2 to 4 months a year, following spring snowmelt and for brief periods after heavy rains. During June 1990, which was exceptionally wet, the entire lake bed was submerged to an estimated maximum depth of 20 to 30 centimetres. The pH was 7.4 to 7.6. In contrast, in June 1988, the lake bed was already dry mud with small residual pools with waters having a pH of 8.7. The lake bed is usually ice covered from November until late March.

DEPOSITIONAL SUBENVIRONMENTS

Milk Lake is a typical Cariboo playa with three main depositional subenvironments (Figure 3-3-3). The centre of the basin is a broad mudflat that is seasonally occupied by an ephemeral lake. This passes transitionally into peripheral mudflats that, in turn, give way to vegetated hillslopes.

HILLSLOPE

The grass and tree-covered hillslopes are predominantly sites of erosion. Siliciclastic sediment is moved to the adjacent mudflats by slopewash. Periodically, small slumps and arcuate slope failures occur, projecting as lobes onto the mudflats and exposing the glacial sediments to rapid erosion. As the slopes retreat, coarse gravels remain as surficial lag aprons along the base of slope.

PERIPHERAL MUDFLAT

The contact between the hillslope and the peripheral mudflat is commonly abrupt. The peripheral mudflats are a site of extensive magnesium carbonate precipitation. They are a zone where groundwater fluctuates at or close to the surface and is seeping basinward.

The peripheral mudflats are usually zoned with several types of surface (Figure 3-3-3). Below relatively steep hillslopes, the junction may be marked by dense, reedy vegetation; locally, there is standing water. This passes lakeward into a zone of vegetated hummocky ground on which subcircular earthy hummocks rise up to 40 centimetres above the damp intervening hollows. The mounds range from 20 to 100 centimetres in diameter. Most hummocks are partially covered by pink and orange, leathery microbial (cyanobacterial) mats, 1 to 2 centimetres thick.

Sediments in this zone are typically a mixture of slope-derived siliciclastic detritus, mixed with precipitated magnesium carbonates, and are commonly rich in organic matter. They are massive to crudely bedded, may be granular, and are commonly disrupted by roots. Along the southern shore, three main units can be recognized in the upper metre: an upper, dark grey stromatolitic carbonate layer; a brown, middle clastic unit with grey carbonate mottling and macrovegetal remains; and a lower, pale grey to cream carbonate layer (Figure 3-3-3). The intervening hollows are commonly rich in stromatolite intraclasts. This zone ranges in width from a few metres to approximately 20 metres, and is typically 5 to 10 metres wide.

Beyond the vegetated hummocks, there is usually a zone of white hummocky ground composed predominantly of magnesium carbonates. This differs from the former by being purer carbonate (often greater than 95%), having far less surficial vegetation, and displaying a more regular polygonal pattern (Plates 3-3-1 and 2). The subcircular hummocks ("cauliflowers" of Cummings, 1940) rise from a few decimetres to a metre above normal maximum lake level. They are typically 50 to 120 centimetres across, and separated by narrow, often damp depressions, normally with tufted grasses. The hummock surfaces have stromatolitic crusts 1 to 2 centimetres thick that break up as the surface dries out, producing intraclasts and finely powdered mud. Below these friable crusts, there is a layer of grey to white, mottled massive carbonate mud, that progressively becomes more cream in colour and granular at depths of 60 to 80 centimetres.

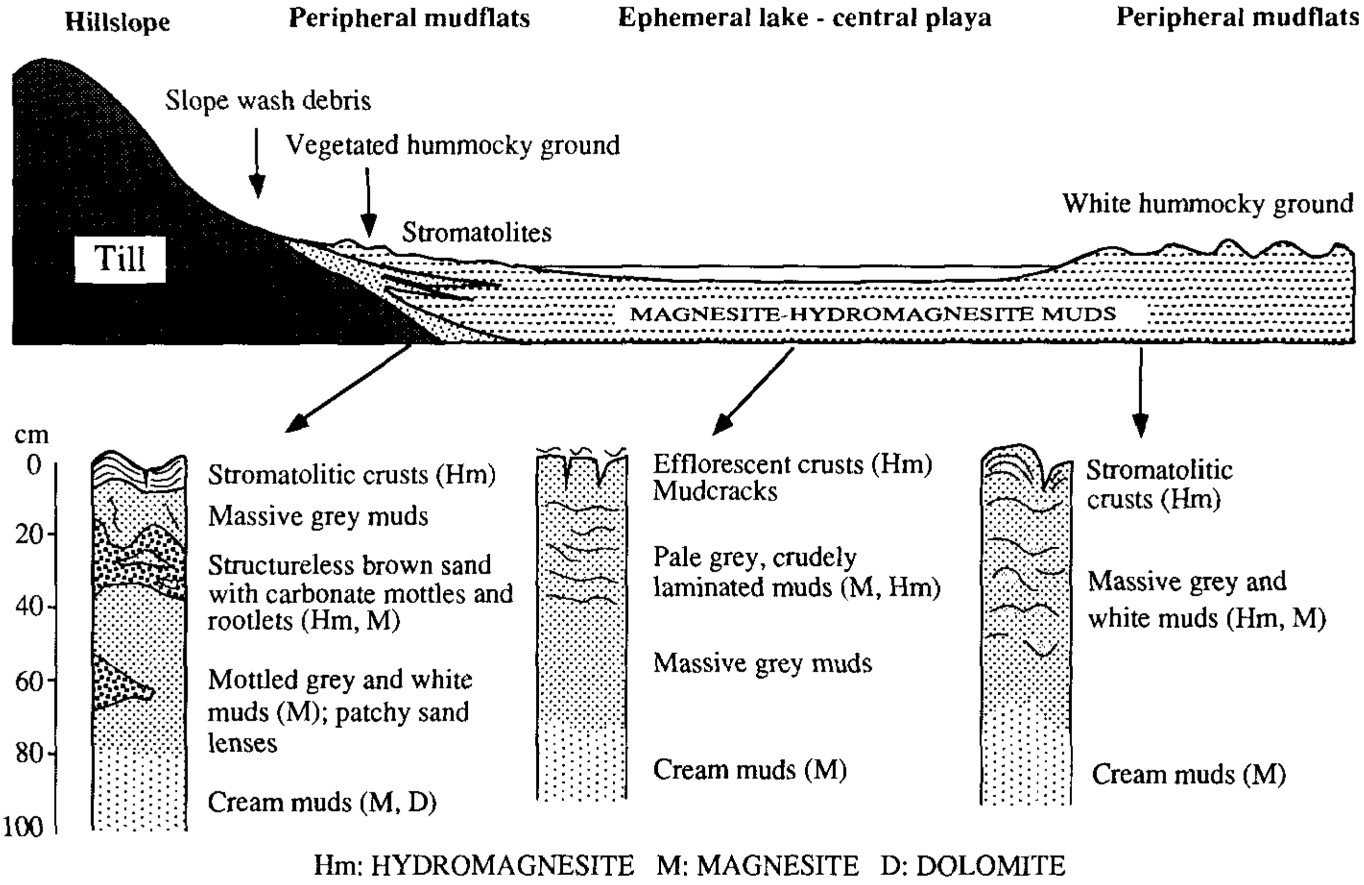

Figure 3-3-3. Schematic section through the southern margins of Milk Lake, showing selected profiles through the near-surface sediments.

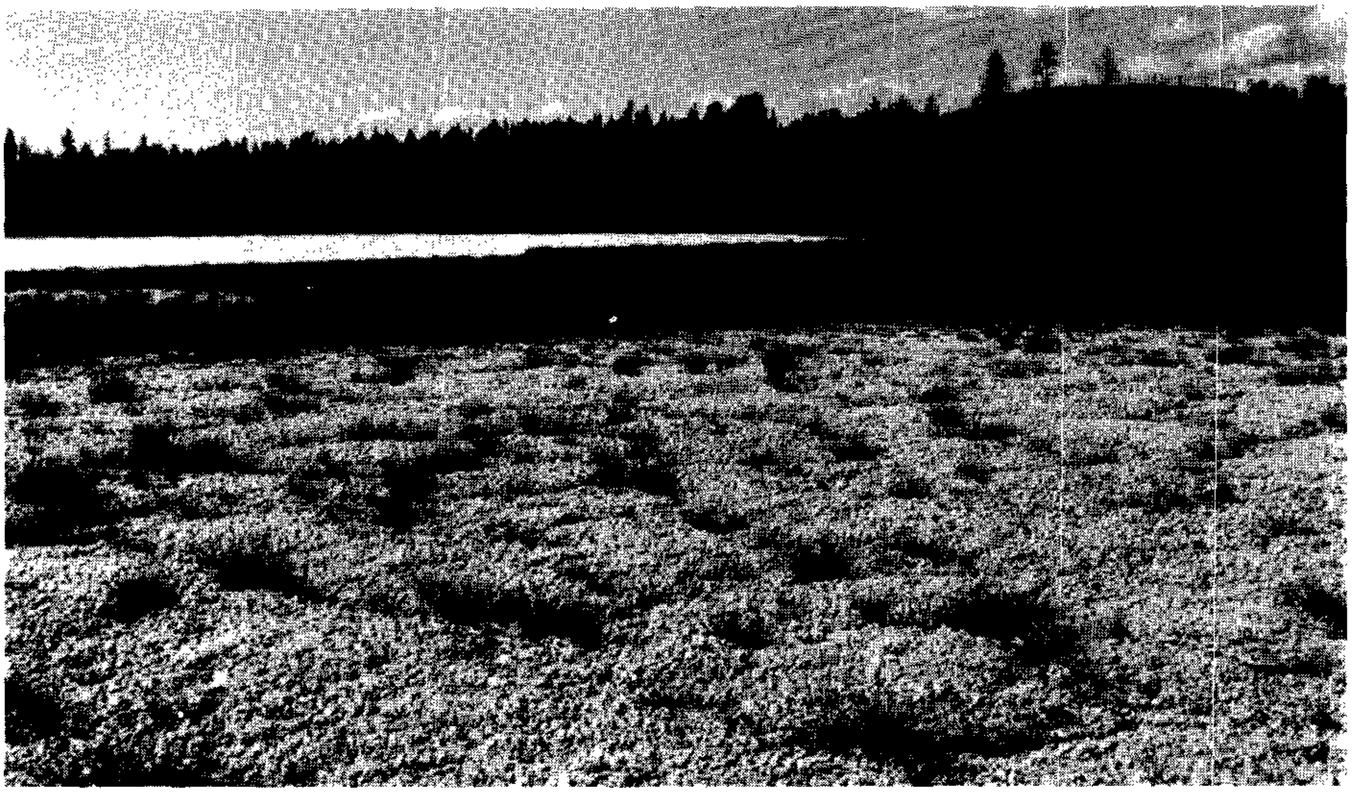

Plate 3-3-1. White hummocky ground (hydromagnesite) at the southeastern margin of Milk Lake. The upper surface of the hummocks is composed of desiccated, fragmented microbial mats. The Alberta Lake esker is visible in the background.

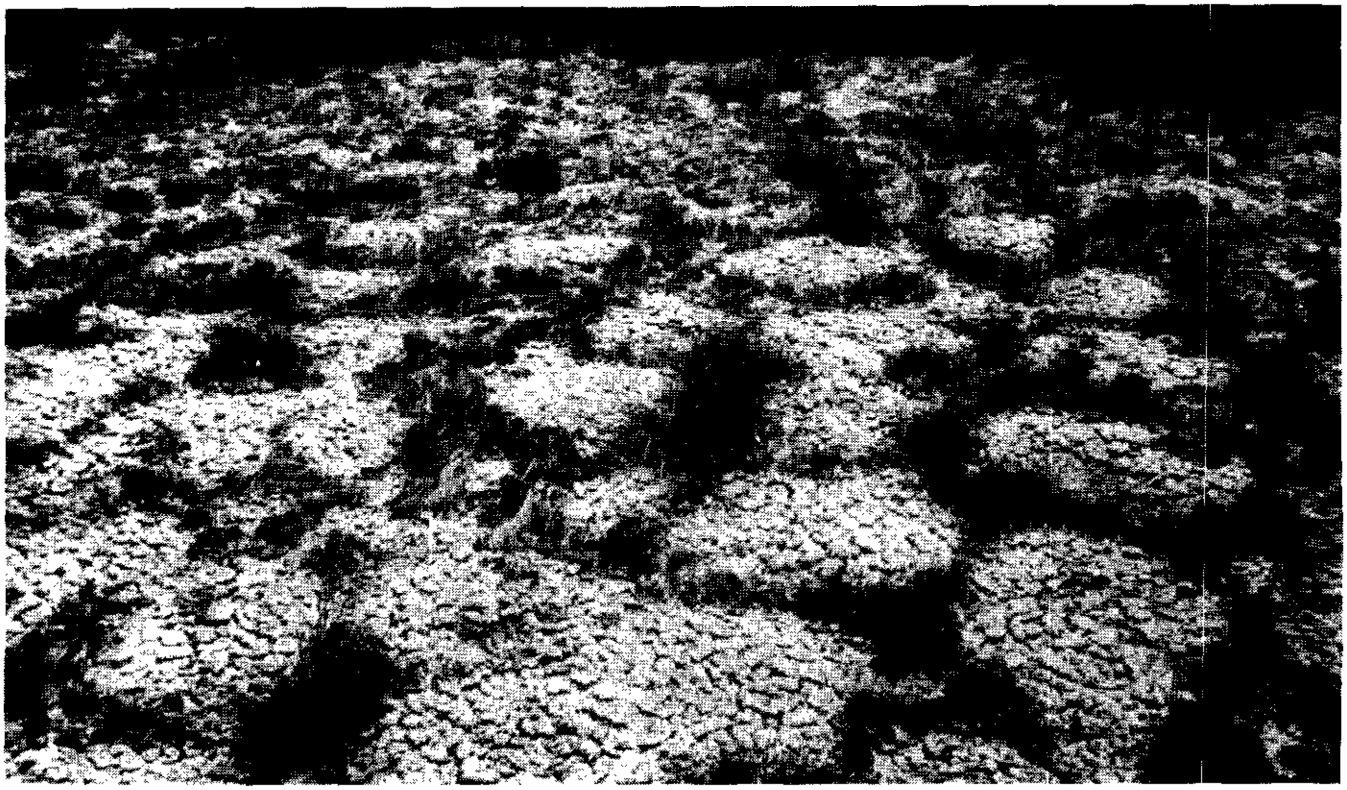

Plate 3-3-2. White hummocky ground (hydromagnesite) between Milk Lake and Slime Lake, showing polygonal pattern. Polygon at bottom centre is about 80 centimetres in diameter.

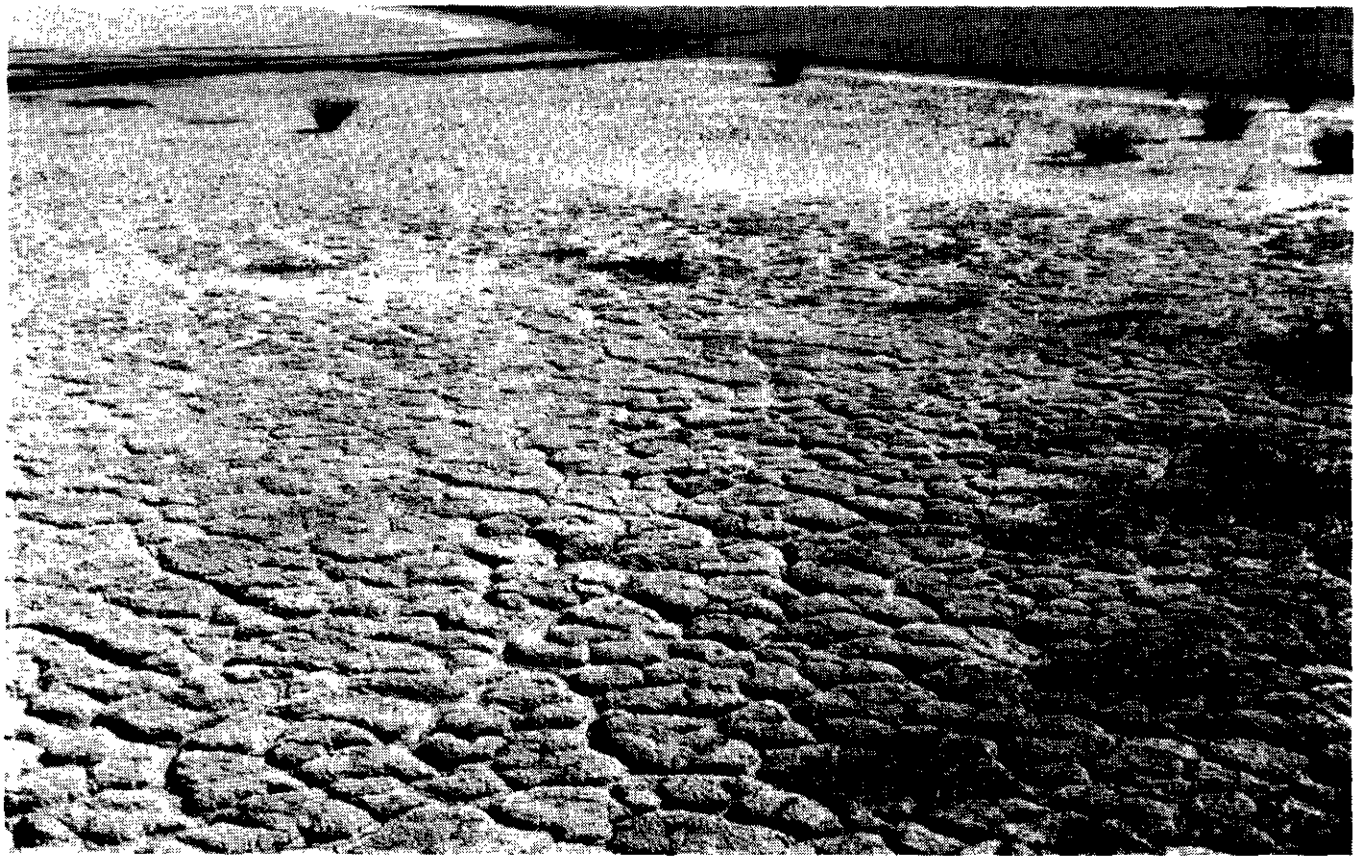

Plate 3-3-3. Hydromagnesite stromatolites on the southern margin of Milk Lake, which is visible at top right. Tufts of grasses are about 30 centimetres high.

This type of surface is common to most hydromagnesite-magnesite deposits across the plateau, including those at Meadow Lake, Watson Lake, Sixtyone Creek and Clinton Lake (Reinecke, 1920; Cummings, 1940; Renaut and Stead, 1990). This zone is not continuous around most lakes. It typically develops on mudflats at the extreme ends of elongate lakes, and may separate adjoining playa basins, as for example, between Milk Lake and Slime Lake (Figure 3-3-2).

Toward the shoreline, hummocky ground gives way to a broad zone of microbial mats (stromatolites) with extensive mudcracks (Plate 3-3-3). During June 1990 this zone was 5 to 20 metres wide and extended for at least 2 metres offshore. The stromatolites themselves show morphological zonation from broadly domal and pustular mats to nearly horizontal mats as the shoreline is approached. Sediments in the upper metre of this zone are typically white and grey, massive muds, locally with stromatolite intraclasts, becoming cream coloured at depth. Significantly, all the microbial mats of the peripheral mudflat were developed above the maximum lake level for spring of 1990.

CENTRAL MUDFLAT

The central mudflat, when dry, is a hard, flat surface of pale grey carbonate muds showing extensive, dense, small (2 to 20 cm) polygonal mudcracks. A few larger crack networks also develop 2 to 4 metres apart. Although generally flat, small saucer-like depressions a few metres across and less than 10 centimetres deep, are scattered across the surface. They are commonly damp and are visible on aerial photographs. It is unclear whether these are loci of upward groundwater seepage or withdrawal, or both. Recessional strandlines, marked by concentrations of vegetative and/or microbial debris, and, more rarely, small (1 to 2 cm) wave-cut notches, are also present. Shallow rills less than 5 centimetres deep and from 10 to 50 centimetres wide, are found normal to the recessional shorelines. White efflorescent carbonate crusts from 1 to 10 millimetres thick develop locally, particularly toward the shoreline.

A shallow pit dug near the centre of the playa muds during June 1988 revealed massive grey muds which continue to a depth of at least 80 centimetres, becoming mottled with whiter patches and lenses 40 to 60 centimetres below the surface, and cream at about 1 metre. Samples allowed to dry at room temperature, and split subvertically with respect to the lake bed, revealed a crude, but disrupted, coarse (0.5 to 1 cm) lamination.

INTERBEDDED CARBONATES AND SILICICLASTICS OF THE NORTHERN LAKE MARGINS

The gentle grassy slopes along the northwestern playa margins are underlain by massive to weakly bedded, grey and white, magnesium carbonate muds that interfinger with slope-derived siliciclastic sands. The carbonates lie up to a metre above the adjacent playa mudflats and, unlike the other playa margins, they are incised by broad shallow gulleys. They are also truncated by an erosional bluff along the modern littoral zone. Hummocky ground is only well developed close to the modern maximum level shoreline.

The significance of these sediments is uncertain. Although carbonates may be forming near the shore zone, the eroding sediments upslope may be somewhat older than those elsewhere in the basin.

MINERALOGY

Preliminary analyses of the mineralogy of 30 bulk samples of the carbonate muds were made by X-ray diffraction. Samples were prepared as cavity mounts and analysed using a Rigaku X-ray diffractometer with Cu K-α radiation. These have confirmed that the muds are predominantly magnesite ($MgCO_3$) and hydromagnesite ($Mg(OH)_2 \cdot 4MgCO_3 \cdot 4H_2O$) (Figure 3-3-4). Dolomite is present in two of the muds. Although the sample size is still small, several trends in the mineral distribution are apparent.

Hydromagnesite is the dominant, and commonly the only, mineral in the stromatolites and surficial efflorescent crusts that surround the lake. Hydromagnesite, normally mixed with some magnesite, is also the principal carbonate in the upper 10 to 30 centimetres of the zones of white hummocky ground. The carbonates interbedded with siliciclastics along the northern shore are a mixture of hydromagnesite and magnesite, the latter increasing downward in the profile.

Magnesite is the principal carbonate in the modern ephemeral lake muds. It is found at the surface of the dry lake bed (or below a thin, ephemeral hydromagnesite efflorescence) and continues to depths of at least 80 centimetres. Hydromagnesite was found in two cores at depths of 10 to 20 centimetres below the central playa surface, accounting for about 25 to 30 per cent of the total carbonate.

Magnesite also occurs in the peripheral mudflats. Although an accessory in some surficial crusts and stromatolites, it usually increases in abundance about 20 to 30 centimetres below the surface, down to about a metre, occurring as the only carbonate or accompanied by minor hydromagnesite or dolomite.

Partially ordered dolomite occurs at a depth of 40 to 80 centimetres below the stromatolites in the southern peripheral mudflat sediments, associated with magnesite (Figure 3-3-4). At Milk Lake, no other carbonate minerals were found in the initial batch of samples analysed. However, in the Clinton Lake basin (Figure 3-3-1), where similar hydromagnesite-magnesite muds are forming, aragonite, calcian dolomite and magnesian calcite are found mixed with hydromagnesite in peripheral mudflats (Renaut and Stead, 1990; Renaut *et al.*, in press). Nesquehonite ($MgCO_3 \cdot 3H_2O$) and huntite [$CaMg_3(CO_3)_4$] have been recorded from unnamed carbonate playas a few kilometres west of 70 Mile House.

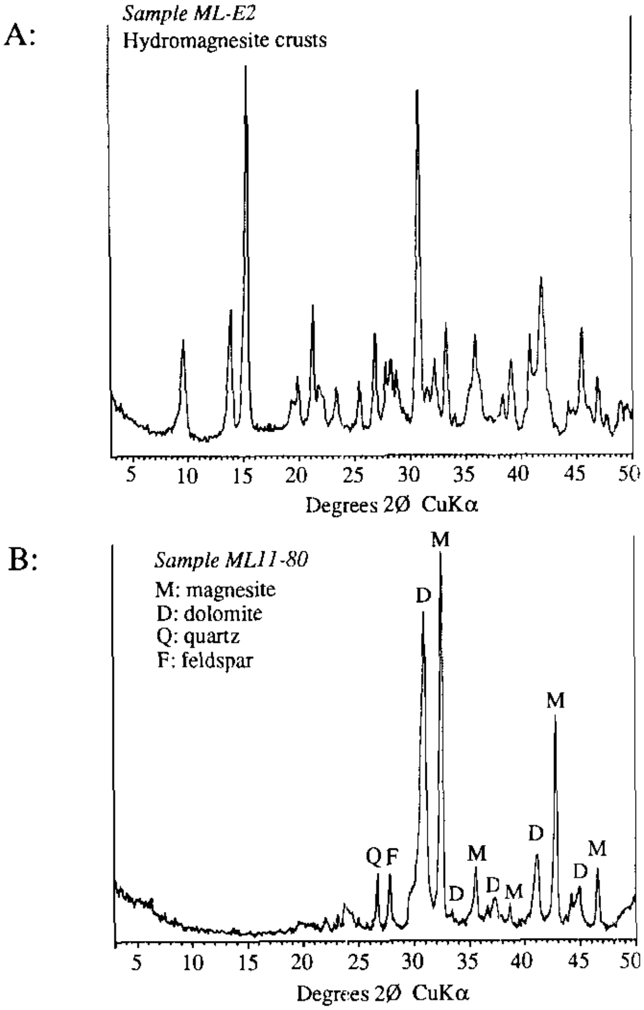

Figure 3-3-4: X-ray diffractograms of Milk Lake carbonates. A: Hydromagnesite crusts from white hummocky ground southeast of the lake; B: Magnesite-dolomite muds from 80 centimetres depth in a pit located in the peripheral mudflats of the southern shoreline.

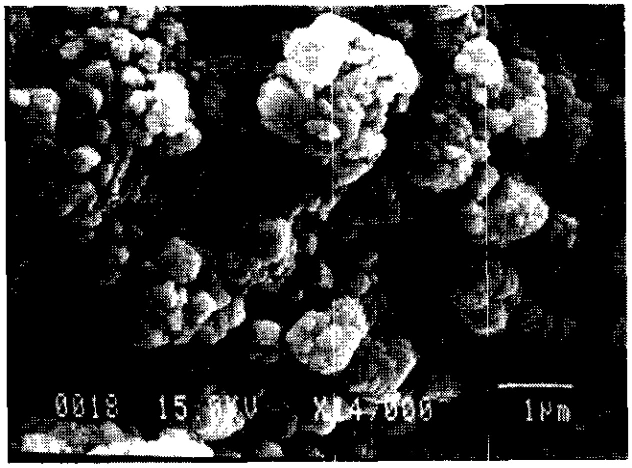

Plate 3-3-4. Scanning electron microscope photomicrograph showing aggregates of magnesite-hydromagnesite crystals, from a depth of 20 centimetres, central playa.

Four lacustrine muds were examined using a scanning electron microscope (Plate 3-3-4). They show that the muds are extremely fine grained. For both magnesite and hydromagnesite, individual crystals range from subhedral to anhedral and are less than 1 micron. Most occur as aggregates from 0.5 to 2 microns across.

The carbonates of the central mudflat are relatively pure. The acid-insoluble fraction of four samples ranged from 1.2 to 5.4 weight per cent. The principal impurities are clay minerals (mostly smectite), plagioclase silt, corroded diatom debris and organic detritus.

The peripheral mudflats generally contain a higher percentage of non-carbonates, reflecting detrital wash from adjacent slopes. The principal non-carbonate minerals detected by X-ray diffraction are plagioclase, quartz and clay minerals. Preliminary results suggest that smectites predominate (14Å). Palygorksite, sepiolite and opal-A have been found in samples from mudflats west of Meadow Lake, and may account for the silica reported in hydromagnesite analyses by Reinecke (1920) and Cummings (1940).

ORIGIN OF THE MAGNESITE-HYDROMAGNESITE DEPOSITS

Magnesite and hydromagnesite deposits have been described from playa lakes on several continents. Both primary and diagenetic origins for the minerals have been proposed (*e.g.* von der Borch, 1965; Irion and Müller, 1968; Müller *et al.*, 1972; Popov and Sadykov, 1987; Pueyo-Mur and Ingles-Urpinell, 1987; Molnar, 1990).

Although analyses are at a very preliminary stage, and chemical analyses of the basin waters are incomplete, the field evidence indicates that the magnesium carbonates are probably forming today. Magnesium-rich groundwaters are discharging into the basin, and through evaporation and/or biomediation, magnesite and hydromagnesite (and/or possibly a calcium-bearing precursor) are forming both in peripheral mudflats and within the central playa-lake.

The groundwaters acquire a high magnesium/calcium ratio on contact with the underlying basaltic rocks, and by widespread precipitation of calcite and magnesian calcite in soils and near-surface sediments (Renaut, 1990b). Previous analyses of Cariboo groundwaters have revealed magnesium/calcium ratios of 1.5 to 41, and salinities from <1 to 40 g L^{-1} TDS (unpublished data). Although the hydrogeology is poorly understood, they move basinward through permeable layers within the tills and glaciofluvial deposits, or at their contact with the underlying lavas. Elsewhere on the plateau, especially along paleomeltwater channels, permeable sands and gravels underlie playa sediments and may also do so at Milk Lake.

In the peripheral mudflats, shallow groundwaters seeping lakeward undergo capillary evaporation and perhaps degassing of carbon dioxide. Hummocky and self-rising ground are commonly associated with groundwater discharge in the capillary fringe (*e.g.* Motts, 1970). The upward growth of hummocks may be related to interstitial carbonate precipitation within granular permeable sediments.

Hydromagnesite appears to be forming today at or close to the surface as a product of complete evaporation. Whether associated cyanobacteria mediate in precipitation is uncertain, but scanning electron microscope examination has shown that their filaments and mucilage are heavily encrusted by hydromagnesite.

The origin of the underlying magnesite and dolomite requires investigation. Cummings (1940) noted a common downward increase in calcium content of the muds which he attributed to differences in solubility, the calcium-bearing carbonates being first to precipitate from waters progressively concentrated as they are drawn upwards. There are, however, other possibilities that require testing. For example, groundwater composition may have varied through time as a result of a climatic change. A relative increase in evaporation, for example, might increase early calcium carbonate precipitation in soils, thereby increasing the magnesium/calcium ratio of the groundwaters. Dolomitization of a calcium carbonate precursor might result, and magnesium carbonates could precipitate. The common downward transition from hydromagnesite to magnesite may be diagenetic, due to dewatering of original hydromagnesite, which is the metastable phase (Christ and Hostetler, 1970). The effects of seasonal changes in groundwater composition, already noted in other lake basins (Renaut, 1990b), and flushing of the sediment by runoff are also unknown.

Most carbonate precipitation within the lake occurs as it gradually desiccates from its maximum level during May and June. During June 1990, the lake waters were milky with a fine suspension of white carbonate crystals and had a pH of 7.6.

A preliminary examination by scanning electron microscope of a small filtered sample collected at the shoreline revealed very fine aggregates of subhedral magnesium carbonate crystals, the individual crystals being less than 0.5 micron in diameter. Qualitative energy-dispersive analyses (EDS) on a JEOL JXA 8600 microprobe, confirmed that these are calcium-free. X-ray diffraction analysis of a smear of the very small sample produced a dominant, but weak, reflection at 2.735 Å, suggesting that they are magnesite, but further confirmation is required. Whether this is evidence of primary precipitation of magnesite, or resuspension of bottom muds, awaits investigation.

Although evaporative concentration and warming are probably important factors in precipitation, biomediation may also occur. During June and July, the waters were locally green with dense blooms of algae and cyanobacteria. Photosynthetic assimilation of carbon dioxide may, therefore, contribute to carbonate precipitation (*e.g.* Kelts and Hsü, 1978). Recently, Thompson and Ferris (1990) demonstrated cyanobacterial mineralization of magnesite in the laboratory and speculated that it may occur in high pH (8.5 to 10), saline aquatic environments, such as Milk Lake.

It is unclear whether magnesite is the initial and only precipitate, or whether hydromagnesite also precipitates from the lake waters or central playa groundwaters after the lake desiccates. Elsewhere on the plateau, hydromagnesite is apparently precipitating from lake water. In a small gravel-pit pond 1 kilometre west of Clinton Lake, brief whitings of hydromagnesite have twice been observed during early summer. The sediments are nearly pure aggregates of hydromagnesite.

CONCLUSIONS

Magnesite and hydromagnesite are forming today at Milk Lake and in many other playa basins on the Cariboo Plateau. At Milk Lake, hydromagnesite is precipitating as surficial crusts from shallow magnesium-rich groundwaters in the capillary fringe of peripheral mudflats, and is commonly associated with cyanobacterial mats. It overlies magnesite and dolomite at a few decimetres depth.

Subaqueous precipitation of magnesium carbonates occurs in the desiccating playa lake, by evaporative concentration and possibly by biomediation. The original precipitate remains to be determined. The central playa muds are relatively pure and dominated by magnesite with subsidiary hydromagnesite.

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